

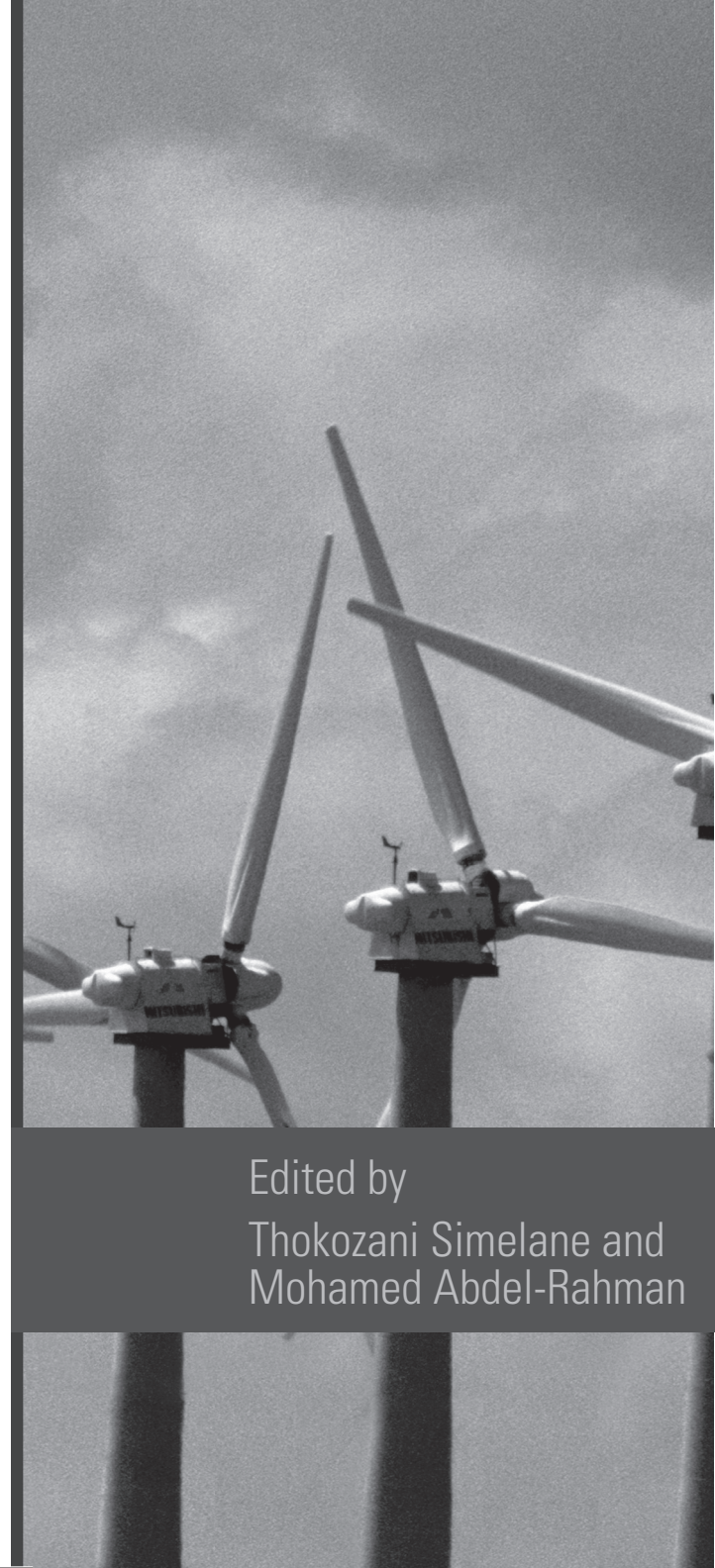
A photograph of several white wind turbines against a cloudy sky. The turbines are positioned diagonally, with their blades pointing upwards and outwards. The sky is a mix of light and dark grey clouds.

ENERGY TRANSITION IN AFRICA

Edited by
Thokozani Simelane and
Mohamed Abdel-Rahman

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A black and white photograph of several wind turbines. The turbines are white with three blades each. The blades are positioned at different angles, some pointing upwards and others downwards. The nacelles (the central part of the turbine) are visible, with the name 'NORDEX' printed on them. The background is a cloudy sky. The image is split vertically, with the left half showing the turbines and the right half being white.

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Energy Transition in Africa

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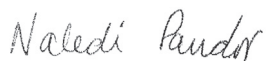
Foreword

The prevailing period of energy transition provides a myriad development opportunities for Africa. To capitalise on the opportunities presented, Africa needs to understand its strengths and capabilities of the role it is going to play in a global economy driven by renewable energy sources. Africa has the advantage of migrating to renewable energy sources, and thus becoming a major supplier of renewable energy to the world. Unlike most developed countries, Africa has a minimal investment locked into fossil-fuel-based energy sources. It is naturally endowed with various sources of renewable energy and thus has an opportunity to lead the field in the provision of renewable energy. But to achieve this Africa needs to develop or acquire technologies that will be relevant and affordable, design strategies that will guide the process of migrating to renewable sources of energy, reduce high levels of illiteracy among the users of the technologies to be deployed, and invest in the infrastructure that will be required to migrate to renewable sources of energy.

This book discusses all these matters and is thus of interest to readers in all African countries, and indeed further abroad. It also provides an interesting account of how Africa has lost out on nuclear energy. This raises a strong warning that Africa must not step aside when the rest of the world is developing its capacity in search for alternative sources of energy. While Africa's inability to benefit from its large deposits of uranium can be attributed to the high cost of nuclear power, a closer examination of the development of Africa's nuclear capabilities reveals considerable social and economic dynamics that relentlessly undermine its scientific and technological advancement. At this crucial moment in energy transition, I trust that Africa is not going to repeat the mistakes of the past. I have found the contents of this book interesting in that they highlight Africa's strength in participating in renewable energy developments, the scale of investment needed, human capital requirements and the technological options that are available to Africa.

I would like to thank the Africa Institute of South Africa for contributing to the development of knowledge about and for Africa, and I

encourage it to continue to do so, especially using the innovative model of working with African scholars across the continent and the diaspora to make the vision of the twenty-first century an African century. I hope that academics, policy makers and the public will find this publication a useful reference in the course of their work or general reading interests.

A handwritten signature in dark ink, reading "Naledi Pandor". The script is cursive and fluid, with the first name "Naledi" and the last name "Pandor" clearly distinguishable.

Naledi Pandor
Minister of Science and Technology
South Africa

Preface

The world's energy consumption and demand is increasing exponentially. In 2007, the world consumed an estimated 18 trillion kWh of generated energy. By 2030, the demand for energy will have increased to 31 trillion kWh, of which an estimated 20 trillion will be generated from renewable sources. Of critical concern is that the world's supply of fossil fuels and its reserves are decreasing, and locating new reserves has become difficult. Thus it is imperative to explore renewable sources of energy. The need to migrate to renewable energy is further driven by people's desire and commitment to halt climate change and its effects.

This shift in energy sources pose both a challenge and opportunity for Africa, as it will need substantial investment in infrastructure, technology and human capital to be able to catch up with the international trends of generating and supplying energy from renewable sources. Africa has the advantage that it is endowed with abundant sources of renewable energy, which, if fully exploited, can place the continent at the forefront of the world's energy production and supply. An indication of the interest in Africa, is that the Desertec Foundation intends to use solar power generated in Africa to supply Europe with 15 per cent of its energy needs through an investment of €400 billion from 2011 to 2031.

While this appears to hold hope for Africa, the reality is that the continent still has a huge shortage of energy. Only 34 per cent of Africa's population have access to modern forms of energy, with large disparities between countries, and between urban and rural areas within countries. The energy supplies will have to increase at least four- to sixfold by 2025 for the continent to meet its energy needs. Currently, 30 African countries experience chronic blackouts. Therefore power shortages are the single most debilitating on Africa's economic growth.

The most severe challenges facing Africa with regard to energy generation include inadequate development of the energy infrastructure, high capital costs attached to energy projects, the lack of finance and investment in energy projects, and lack of technical expertise. Solving these problems will require efficient planning, investment and efficient

use of resources. Poor planning complicates Africa's energy problem, which is directly linked to the outdated infrastructure, technologies and insufficient expertise and skills to manage the existing infrastructure. We therefore need to develop a thorough understanding of possible directions that Africa can follow.

This book opens a debate on how Africa can develop the right combination of infrastructure, resources, investment and human capital to generate sufficient energy for itself from renewable sources, while supplying the surplus to the rest of the world. The topology of the power system is transforming, as new concepts, such as smart grids, micro-grids and mini-grids, are introduced.

The book is therefore published at a critical juncture, as African governments, foreign investors and private investors are poised to roll out renewable energy projects across the continent. The overall objective of this book is to provide a background and predictions for strategists to develop a master strategy for energy generation and distribution in Africa at this moment of energy transition from fossil fuels to renewable energy sources and technologies.

The debate must occur at all levels, from governments working in regional power pools to engineers and investors to end-users. Generally, the inadequacy in providing conclusive information about energy demand, production and supply in Africa has restricted the development of a broader understanding of the dynamics of the continent's energy needs and scarcity.

Acknowledgements

This book came as a suggestion from Mr Jurgen Knop who suggested that there is a need to develop a route for Africa's transition to renewable energy. His main observation was that Africa has the potential to lead the world in the production and supply of renewable energy.

Putting the book together would have been an unachievable task had it not been for the efforts of the following individuals:

- Mr Shingirirai Mutanga, project manager
- Ms Nomasonto Magano, project assistance
- Ms Amanda Short, research administrator

These individuals, together with the constant support from AISA's Publications Division, oversaw the processes that ensured that the book goes through the required stages of its development. They are all equally acknowledged for their continued support. The editors also thank the authors for their input. Without them, this book would have remained locked in its conceptual stage. The financial support for the book was provided by the Africa Institute of South Africa together with the Department of Science and Technology.

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Abbreviations and Acronyms

AC	alternating current
ACAD	African Carbon Asset Development
ADF	African Development Fund
AEB	Atomic Energy Board (South Africa)
AEC	Atomic Energy Corporation (South Africa)
AfDB	African Development Bank
ANC	African National Congress
Armcor	Armaments Corporation of South Africa
AU	African Union
AUC	African Union Commission
AVLIS	atomic vapour laser isotope separation
b/d	barrels per day
bcm	billion cubic metres
BP	British Petroleum
Btu	British thermal unit
CANDU	Canada Deuterium Uranium
CAPP	Central African Power Pool
CAR	Central African Republic
CDER	Centre for the Development of Renewable Energy (Morocco)
CDM	Clean Development Mechanism
CER	certified emission reduction
CHET	Centre for Higher Education Transformation
CIA	Central Intelligence Agency
CO ₂	carbon dioxide
COMESA	Common Market for Eastern and Southern Africa
CRSES	Centre for Renewable and Sustainable Energy Studies (South Africa)
CSIR	Council for Scientific and Industrial Research (South Africa)
CSP	concentrated solar power
DC	direct current
DNA	deoxyribonucleic acid
DRC	Democratic Republic of the Congo

DST	Department of Science and Technology (South Africa)
DTI	Department of Trade and Industry (South Africa)
EAPP	East African Power Pool
ECCAS	Economic Community of Central African States
ECOWAS	Economic Community of West African States
EIA	Environmental Impact Assessment
ESEMAP	Energy Sector Management Assistant Program
Eskom	Electricity Supply Commission (South Africa)
EU	European Union
FANR	Food, Agriculture and National Resource Directorate
FDI	foreign direct investment
FRELIMO	Frente de Libertação de Moçambique (Liberation Front of Mozambique)
ft ³	cubic foot
FTS	Fischer-Tropsch Synthesis
GDP	gross domestic product
GHG	greenhouse gas
GW	gigawatt
HEU	highly enriched uranium
HPS	hydropower station
HRD	human resource development
HVDC	high voltage direct current
IAEA	International Atomic Energy Agency
ICA	Infrastructure Consortium for Africa
IEA	International Energy Agency
IFI	international finance institution
IISD	International Institute for Sustainable Development
IMC	Industrial Modernisation Centre (Egypt)
IMF	International Monetary Fund
IP	intellectual property
ISES	International Solar Energy Society
KARADEA	Karagwe Development Association
KSTF	Karagwe Development Association Solar Training Facility
kV	kilovolt
kWh	kilowatt hour
kWp	kilowatt-peak
LEU	lowly enriched uranium
LVRT	Low Voltage Ride Thru
MDG	millennium development goal
MED-EMP	Euro-Mediterranean Energy Market Integration Project

MeV	million electron volts
MLIS	molecular laser isotope separation
MPLA	Movimento Popular de Libertação de Angola – Partido do
Trabalho	(People’s Movement for the Liberation of Angola – Labour Party)
Mt	megatonne
Mtoe	million tonnes of oil equivalent
MW	megawatt
NARUC	National Association Regulatory Utility Commissioners
Necsa	South African Nuclear Energy Corporation
NG	natural gas
NGL	natural gas liquids
NGO	non-governmental organisation
NP	National Party
NPT	Nuclear Proliferation Treaty
NREA	New and Renewable Energy Authority (Egypt)
NSTF	National Science and Technology Forum (South Africa)
O&M	operations and maintenance
OAU	Organization of African Unity
OECD	Organisation for Economic Co-operation and Development
OMVG	Gambia River Basin Development Organisation
OMVS	Senegal River Development Organization
OPEC	Organization of the Petroleum Exporting Countries
PBMR	Pebble Bed Modular Reactor
PHES	pumped hydro energy storage
PLO	Palestinian Liberation Organization
PNE	peaceful nuclear explosives
PPA	power purchase agreement
PV	photovoltaic
PWS	pumped water storage
R&D	research and development
RCECS	river current energy conversion systems
Rd&d	research, development and demonstration
RENAMO	Resistência Nacional Moçambicana (Mozambican National Resistance)
RET	renewable energy technology
RIIC	Rural Industries Innovation Centre
ROR	rate of return
SADC	Southern African Development Community
SADF	South African Defence Force

SAPP	Southern African Power Pool
SCE	Supreme Council of Energy (Egypt)
SELF	Solar Electric Light Fund
SHP	small hydropower system
SME	small and medium enterprise
SSA	sub-Saharan Africa
T&D	transmission and distribution
TEPCO	Tokyo Electric Power Company
TNT	trinitrotoluene
TPES	total primary energy supply
TRIGA	Training, Research and Isotope production and built by General Atomic
TWh	terawatt hour
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNEP FI	United Nations Environmental Programme Finance Initiative
UNITA	União Nacional para a Independência Total de Angola (National Union for the Total Independence of Angola)
USAID	United States Agency for International Development
USEIA	United States Energy Information Administration
USSR	Union of Soviet Socialist Republics
VCUS	Vestas Converter Unity System
WAPP	West African Power Pool
WEC	World Energy Council
WETC	Wind Energy Technology Centre (Egypt)

Introduction

Mohamed Abdel-Rahman and Thokozani Simelane

An Overview of Renewable Energy Production in Africa

Whereas the world has generally progressed rapidly in migrating to renewable energy sources, Africa appears to be lagging behind.¹ The reasons for this include insufficient investment, technological barriers, a lack of political will and incorrect policy options.² All these exist despite the fact that Africa is naturally endowed with various sources of renewable energy.³ The challenge is for Africa to adopt a correct match of technologies and policies, which will allow the continent to migrate successfully to a renewable energy economy.

Africa still relies heavily on technologies that have been developed elsewhere. These often carry the burden of cost and a lack of understanding by local communities,⁴ and are therefore often rejected by them. The effect of this is that the technologies fail to have the desired impact of alleviating Africa's energy scarcity, and as a result Africa continues to be the world's most energy-deprived continent.

Africa needs to view this era of energy transition as an opportunity to introduce new socio-technical systems that will trigger investment and development in the renewable energy sectors.⁵ This means that Africa should embrace energy transition as an opportunity to develop a series of processes and industries that are similar to those developed during the fossil-fuel-based era.⁶

At present, the impact of fossil-fuel industries on social development is most evident in the chemical and energy industries that have resulted from the exploitation of fossil fuels. These include chemical industries which use the basic material content of fossil fuels, ones that synthesise and process a complex array of organic molecules for use as a feed, and industries that manufacture a series of complex organic chemical products and use processes that rely on fossil fuels as a basic feed.⁷ The combined effect of this has been the creation of industries that either supply raw materials or use by-products of refined fossil fuels. All these

combined represent a set of complex industrial systems that emerged from the use of fossil fuels.

Renewable energy, on the other hand, provides an environmentally sound technological platform for Africa. It may offset a significant proportion of foreign exchange that is used to import oil by countries that do not have access to their own sources.⁸ In addition, most renewable energy technologies are inherently modular and are thus well suited to satisfying a decentralised rural energy demand. The modular nature of renewable energy technologies and their low investment cost makes them suitable for capital-constrained African countries.

Africa's Role in Renewable Energy Supply

Renewable energy sources available in Africa include hydropower, biomass, geothermal, wind and solar. Of these, only 5 per cent of Africa's hydropower potential, of just over 1 750 TWh, is being exploited. The total hydropower potential for Africa is equivalent to the total combined electricity consumption of France, Germany, the United Kingdom and Italy.⁹

In the Democratic Republic of the Congo (DRC) the Inga River alone holds great potential, with an estimated output of 40 000 MW. In fact, this river accounts for more than 50 per cent of Africa's hydropower potential. Countries such as Angola, Cameroon, Egypt, Ethiopia, Gabon, Madagascar, Mozambique, Niger and Zambia also have additional hydropower potential.

Abundant biomass is available for providing process heat, gasification, heat cogeneration, liquid-fuel, biogas and solid-fuel production. Several agro-based industries, such as the wood-based industries – palm products, rice mills, sugar, paper and pulp – use their waste to produce both process heat and power, which in most cases is used locally.¹⁰ Cogeneration from agricultural waste has a further potential in Africa. For instance, cogeneration contributes as much as 40 per cent of the total electricity generated in Mauritius. With increased efficiency and better technologies, most facilities can produce significant power for local demand, with additional power sold to the national grid. At present, there are several countries in Africa that produce sugar. These countries have the potential to generate power for their own needs from the by-products of sugar production.

Investment Approach Required to Migrate to a New Energy Paradigm

Harnessing renewable energy resources will certainly not come without a high price tag.¹¹ There is a need to establish an infrastructure that ranges from grid reinforcement to accounting for the specific intermittent nature of renewable resources. The financial resources required exceed the value of the plants. Meanwhile, the limited financing capacity of African countries puts the burden of attracting private finance on some governments.¹² Various studies have been conducted to explore the best ways of establishing synergies between private-sector participation and public capital.

A major advantage of the renewable energy projects is that they are modular. This means that they are able to cater for the participation of small businesses and small investors. Therefore there is a need to design a set of legislative tools within the current policy frameworks to promote the participation of small and medium enterprises (SMEs) in the energy business in Africa. The benefits offered by renewable energy sources compete well with all types of power sources, including hydro-power. The bigger question is how to introduce this business in a manner that will eventually result in a spiral of positive feedback that will trigger economic activities in Africa.

Infrastructure investment characteristics

Private participation in energy infrastructure in Africa is hindered by the characteristics of the infrastructure investment itself, which comprises:

Long-term investment: Infrastructure investment is a long-term commitment with pay-back periods ranging from 15 to 20 years, or even more for mega-projects. This increases the risk to investors. The investor should therefore seek higher returns to use funds efficiently. However, for smaller projects the return on investment period is substantially less and these are less risky than the bigger projects.

Asset specific: An infrastructure investment one makes unfortunately cannot be used in any application other than its original purpose. This makes the whole contract susceptible to leverage application from both parties, whether service provider or off-taker. This is a mutual risk that poses a challenge to investors.

Capital intensive: Energy infrastructure is capital intensive. The business is characterised by a high fixed-to-variable costs ratio. The huge capital required is in most cases a hindrance that prohibits the

participation of small, more liquid investors. Hence, the financing mechanism for mega-projects is large heavy-weight investors. This investment approach requires a syndicated strategy.

In order to overcome these obstacles, one possible approach is to unleash the investment potential of SMEs in Africa. While this needs to be seriously considered, even small private investment comes with numerous prerequisites.

Required human capital development

Developing a consciousness about energy conservation, energy efficiency and the advantages and applications of renewable energy technologies is the key to mobilising human capital into renewable energy.¹³ Energy education programmes should focus on creating a new culture aimed at achieving sustainable energy use.

The mass media, schools and the family should play central roles in this. Targeted messages should promote the creation of a popular energy culture, and inform, persuade, sensitise and educate people. These messages must include the: (a) economic, (b) political, (c) environmental, (d) scientific, and (e) technological aspects of renewable energy. A behavioural change in relation to energy use and conservation is also critical.

Technology and knowledge transfer

Maximising the potential of renewable energy in Africa requires extensive research and development (R&D) activities and increased investment in technology development.^{14,15} Renewables still face many technological obstacles. The fact that the specific energy-generation process – whether wind or solar – is dispersed over relatively large areas in many technologies poses a challenge to modern power systems, since they are designed to operate with large power plants that are area concentrated.¹⁶ The generation technology itself is still far from mature. This presents an opportunity for African research institutions, universities and others to intensify their research on renewables.

Contents of this Book

In the book each chapter explains how Africa should approach the progression from fossil-fuels to renewable sources of energy. Chapter 1

outlines the role of Africa in supplying renewable energy to the world. The chapter highlights sources of renewable energy that are available in Africa. These sources include hydropower, biomass, geothermal, wind and solar. Chapter 2 laments that Africa lacks the capacity to benefit from the diverse sources of energy available, including uranium. The chapter explores historical and contemporary factors to which Africa's under-development may be attributed to. Chapter 3 provides an overview of the state of energy infrastructure in Africa and analyses the amount of investment that is needed to migrate to renewable energy. It argues that securing an affordable modern energy supply is a necessity that will need the participation of governments and the private sector. Chapter 4 outlines the human capital requirement for sustainable renewable energy production and distribution. It asserts that in order to contribute to sustainable renewable energy development, human capital development at all levels – that includes scientists, policy makers and entrepreneurs as well end users – should be prioritised. Chapter 5 assesses the investment requirements for Africa to lead in renewable energy production and distribution. Chapter 6 outlines Africa's technology options for renewable energy production and distribution. The chapter opines that Africa requires a coordinated research and development (R&D) strategy at local, sub-regional and regional levels so as to maximize the comparative advantages that exists at all these levels. It proposes the strengthening of regional integration by creating a regional network of R&D institutions on renewable energy, similar to the global consortium that exists for agriculture.

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Energy revolution in Africa and its future potential in supplying energy to the world

Kamelia Youssef and Shingirirai Mutanga

Introduction

The transition to renewable energy is inevitable. Emerging trends have shown the growing need to use the resources we have in abundance, through clean technology, safe nuclear power, sustainably grown biofuels and the energy we harness from wind, water and the sun. Africa has tremendous untapped renewable energy resources – including hydro, solar, wind, biomass and geothermal – which could be used to produce a large share of the electricity that the continent needs. Each country holds great potential, as the resources are not exploited and used optimally. However, as shown in Map 1 on page 93, the energy resources are unevenly distributed and thus each country has potential in one way or another.¹ As Africa has only 9,5 per cent of the world's proven oil reserves and contributes 12 per cent to global oil production, the need to switch to renewable sources is great. Out of 54 countries only four are exporters of oil, whereas the majority are net energy importers. The renewable energy revolution in Africa could have substantial benefits to the issues of climate change solution and development policy, locally and globally: curbing problems associated with fossil fuels is now a worldwide priority.

This chapter provides an overview of Africa's energy production and supply evolution, the status of energy resources, and the role Africa plays in supplying energy to the world. It also describes the available technology in the production and supply of that energy.

The International Energy Agency (IEA), under the auspices of the Organisation for Economic Co-operation and Development (OECD), stated in 1999 that 'the world is currently in the early stages of a necessary inevitable transition to a sustainable energy system that will be largely dependent on other forms of energy, including renewable resources'.² The following year, the ministers assembled at the G8 Summit in Okinawa Japan recognised for the first time the importance of a renewable energy supply. From the private sector, to governments, to multilateral assistance agencies, renewable energy is receiving increasing investment shares and attention. The great potential of Africa was embraced at the opening of the 25th France–Africa Summit in Nice, France in 2010, by French President Sarkozy, who stated that: 'Africa is our future. The African continent is asserting itself more as a major player in international life.'³

Evolution of Africa's Energy Statistics from 1973 to 2008 (2009)

Primary energy production, supply and consumption in Africa have grown rapidly since 1973.⁴ As shown in Table 1.1 electricity generation increased by 468 per cent. Total primary energy supply (TPES) increased by 213 per cent.⁵ Hydro production increased by 246 per cent.⁶ The total final consumption using fuel increased by 178 per cent. Crude oil, hard coal and natural gas production increased by 65 per cent, 275 per cent and 1955 per cent, respectively. The TPES has increased from 207,9 Mtoe (approximately 3,4% of total world supply) in 1973 to 650,2 Mtoe (approximately 5,3% of total world supply) in 2008.⁷ Natural gas production has increased from 9,8 bcm (approximately 0,8% of total world production) in 1973 to 201,6 bcm (approximately 6,5% of the total world production) in 2009.⁸ Natural gas holds significance as a key substitute for oil products in residential, road transportation and industry usage, and power generation, having high efficiencies and lower environmental impact than oil.

Status of Africa's Energy Resources

Africa is well endowed with fossil energy resources, with a high level of energy self-sufficiency, but these resources are unevenly distributed and concentrated in a few countries.¹⁰ In 2007, conventional liquids production was estimated at 10,5 million b/d (approximately 12,9% of the world total) and concentrated in North Africa and West Africa, with 38,1 per cent and 39,0 per cent, respectively,¹¹ as shown in Table 1.2.

Table 1.1 Evolution from 1973 to 2008 and 2009 of African energy statistics⁹

Type	Unit	1973	2008	2009	Percentage change from 1973 to 2008 (or 2009)
Total primary energy supply	Mtoe	207,910	650,151		213%
Hydro production (including pumped storage)	TWh	28,490	98,640		246%
Refining (includes crude oil, NGL, refinery feedstock, additives and other hydrocarbons)	Mt	46,563	128,469		176%
Electricity generation (excludes pumped storage)	TWh	110,088	625,611		468%
Total final consumption by fuel	Mtoe	173,012	480,396		178%
CO ₂ emission by fuel	Mt of CO ₂	297,217	881,430		197%
Crude oil production	Mt	289,567		476,532	65%
Natural gas production	bcm	9,808		201,565	1955%
Hard coal production	Mt	67,050		251,580	275%

Table 1.2 Conventional liquids productions (2007)¹⁴

Region	Amount (million b/d)	Percentage
North Africa	4,0	38,1
West Africa	4,1	39,0
Rest of Africa*	2,4	22,9
Total Africa	10,5	100,0

* Chad, Congo, Egypt, Gabon, São Tomé and Príncipe, Sudan and other

In 2007, total installed generating capacity was 117 GW, approximately 2,6 per cent of the world total, with coal-fired (35,0%) and natural gas-fired (34,2%) production dominating¹² as shown in Table 1.3.

In 2007, net electricity generation from a central producer was 581 billion kWh, approximately 3,1 per cent of the world total, as shown in Table 1.4. In 2009, natural gas and hard coal productions were estimated to be 201,6 bcm and 251,6 Mt (approximately 6,5% and 4,2% of the world total, respectively), as shown in Table 1.5.

The electrical consumption in Africa is approximately 562 TWh (2008), which represents 3,0 per cent of world consumption. As shown in Table 1.6, the energy consumptions for oil, natural gas, coal, nuclear and renewable resources were represented as 3,6 per cent, 2,9 per cent, 3,2 per cent, 4,6 per cent and 7,6 per cent of the world consumption, respectively.¹³

Table 1.3 Installed generating capacity (2007)¹⁵

Type	Amount (GW)	Percentage
Solar, biomass, geothermal, wind	1	0,86
Nuclear	2	1,71
Liquids-fired	11	9,40
Hydroelectric	22	18,80
Natural-gas-fired	40	34,19
Coal-fired	41	35,04
Total Africa	117	100,00

Table 1.4 Net electricity generation from central producer (2007)¹⁶

Type	Amount (billion kWh)	Percentage
Solar, biomass, geothermal, wind	3	0,52
Nuclear	12	2,06
Liquids-fired	62	10,67
Hydroelectric	97	16,70
Natural-gas-fired	143	24,61
Coal-fired	264	45,44
Total Africa	581	100,00

Advantages of Using Renewable Energy

The reason for using renewable energy is that it is physically renewable. Renewable energy sources are derived from the Earth's ecosystem – primarily from flowing water, solar insulation and, to a lesser extent, from the Earth's geothermal energy.

Renewable energy sources can assist to limit the use of fossil fuels, reduce pollution and lower dependency on imported fuels.

The renewable energy systems that satisfy Africa's energy needs fall into:

Table 1.5 Energy indicators¹⁷

Type	Africa		World
	%	Amount	
Total primary energy supply (2008)	5,3	650,15 Mtoe	12 267 Mtoe
Crude oil production (2009)	12,4	476,53 Mt	3 843 Mt
Natural gas production (2009)	6,5	201,57 bcm	3 101 bcm
Hard coal production (2009)	4,2	251,58 Mt	5 990 Mt
Hydro production (2008)	3,0	98,64 TWh	3 288 TWh
Electricity generation (2008)	3,1	625,61 TWh	20 181 TWh
Total final consumption (2008)	5,7	480,40 Mtoe	8 428 Mtoe
CO ₂ emission by fuel (2008)	3,0	881,43 Mt	29 381 Mt

Table 1.6 Energy consumption (2007)¹⁸

Type	Africa		World
	%	Amount	
Oil	3,60	3,1 million b/d	86,1 million b/d
Natural gas	2,86	3,1 trillion ft ³	108,5 trillion ft ³
Coal	3,17	4,2 quadrillion Btu	132,4 quadrillion Btu
Nuclear	4,63	12,0 billion kWh	259,3 billion kWh
Hydro electricity and other renewable	7,58	3,7 quadrillion Btu	48,8 quadrillion Btu

- large-scale renewable energy systems, such as hydropower, modern biomass, geothermal, wind and solar energy resources, with these being usually grid connected, and
- small-scale energy systems, such as photovoltaic (PV), wind, thermal energy, solar, biogas and small hydropower.

The Status of Africa’s Energy Sector

Africa’s energy sector can be grouped into three distinct categories or regions:

- *North Africa*: this sub-region comprises five middle-income countries (Algeria, Egypt, Libya, Morocco and Tunisia) and is heavily dependent on oil and gas.
- *South Africa*: a country which depends heavily on coal.
- *Sub-Saharan Africa (SSA)*: the vast sub-region below the Arab countries, excluding South Africa and the island states, which are largely dependent on biomass.

See Map 2 on page 94 for the African district regions.

Africa is endowed with enormous renewable energy and non-renewable energy sources. It is estimated that the continent has high potential for hydropower and geothermal power. It also receives excessive solar radiation throughout the year, and high wind energy sources are available along some of the coastal and specific inland areas of Africa. Table 1.7 shows the status of renewable energy in Africa.

Table 1.7 The status of renewable energy in Africa¹⁹

Solar	5–6 kWh/m ² (excellent in North Africa, Sahel, the Horn and Southern Africa)
Wind	3–5 m/s (more than 9 m/s in North, South, West and the Horn) 10–20 000 MW in North Africa
Biomass	Extensive
Geothermal	9 000 MW
Hydro (Large)	Massive, approximately 7% harnessed
Hydro (Small)	Extensive

The Role of Africa in Supplying Energy to the World

The rapid increase in world energy prices from 2003 to 2008, combined with concerns about the environmental consequences of greenhouse gas (GHG) emissions, has led to a renewed interest in the alternatives to fossil fuels – particularly, nuclear power and renewable resources. Interestingly Africa has a big role to play.

Africa has different kinds of energy resources that include fossil oil and renewable energy, as illustrated in Map 1. Table 1.8 represents the conventional liquid production for Africa and total world production over the projection period (2007–2035).²⁰ While the total conventional liquid production is anticipated to increase from 81,4 to 97,7 million b/d by 2035, the political instability in a country such as Libya and the North African region poses some uncertainty. Nonetheless, renewable energy sectors have a huge role to play in national development in terms of job creation and income generation, as well as by providing an environmentally sound energy service. From 2007 to 2035 the world renewable energy use for electricity generation is predicted to grow by an average of 3 per cent per year, and the renewable share of world electricity generation is predicted to increase from 18 to 23 per cent in 2035.²¹

Most of the projected global increase in renewable electricity supply will be fuelled by hydropower and wind power, which together represent 80 per cent of the 4,5 trillion kWh of increased renewable generation over the projection period (2007–2035): 2,4 trillion kWh (54%) from hydroelectric power and 1,2 trillion kWh (26%) from wind. Apart from these two sources, most renewable generation technologies will not be economically competitive with fossil fuels over the projection period, outside a limited number of niche markets.

Tables 1.9 and 1.10 represent the role that Africa will have to play in the production, electricity generation and installed generating capacity, from conventional liquid and renewable sources over the projected period (2007–2035).

Renewable Energy Technologies as Drivers of Africa's Energy Supply

The developing countries of Africa have common locations for the implementation of renewable energy technologies. At present, many

Table 1.8 Conventional liquid production (million b/d)²²

Region		2007	2008	2035	Average annual percentage change 2007–2035
North Africa*		4,0	4,1	4,6	0,5
	Algeria	2,2	2,2	3,0	1,2
	Libya	1,8	1,9	1,6	- 0,5
West Africa*		4,1	4,2	5,1	0,8
	Angola	1,8	2,0	2,1	0,6
	Nigeria	2,4	2,2	3,0	0,9
Africa		2,4	2,4	3,2	1,0
	Chad	0,1	0,1	0,1	- 3,4
	Congo (Brazzaville)	0,2	0,2	0,2	0,0
	Egypt	0,7	0,6	0,7	0,1
	Equatorial Guinea	0,4	0,4	0,3	- 0,3
	Gabon	0,2	0,2	0,2	- 1,4
	São Tomé and Príncipe	–	–	0,1	–
	Sudan	0,5	0,5	0,9	2,4
	Other	0,3	0,3	0,8	3,3
Total Africa		10,5	10,7	12,9	–
Total world		81,4	81,6	97,7	0,7

* In Organization of the Petroleum Exporting Countries (OPEC-12)

Table 1.9 Net electricity generation from central producer in Africa (Billion kWh)²³

Type	History	Projections	Average annual percentage change (2007–2035)
	2007	2035	
Liquid-fired	62	47	- 1,0
Natural-gas-fired	143	471	4,4
Coal-fired	264	468	2,1
Nuclear	12	31	3,5
Hydroelectric	97	166	1,9
Wind power	1	8	7,4
Geothermal	1	3	4,5
Solar	0	7	21,4
Biomass, waste, tidal/wave/ocean	1	1	2,6
Total Africa	581	1 202	2,6
Total world	18 783	35 191	2,3

countries already have small-scale solar, hydropower, wind and geothermal devices in operation that provide energy to their urban and rural populations. These types of energy production are useful in remote areas, because of the very high cost of transmitting electricity from large-scale power plants. The implementation of renewable energy technologies has the positive potential to make Africa one of the major suppliers of renewable energy.

Hydropower

Hydropower is a renewable, economic, non-polluting and environmentally moderate source of energy. Hydroelectric projects have long useful lifespans of more than 50 years and assist in saving scarce depletable fossil fuels. Hydropower stations have improved the ability to start and stop instantaneously and to manage power variations to improve reliability of the power system, and have become the best choice to match peak demand.

Table 1.10 Installed generating capacity in Africa (GW)²⁴

Type	History	Projections	Average annual percentage change (2007–2035)
	2007	2035	
Liquid-fired	11	8	- 1,0
Natural-gas-fired	40	82	2,6
Coal-fired	41	70	1,9
Nuclear	2	4	3,0
Hydroelectric	22	42	2,4
Wind power	0+	3	6,6
Geothermal	0	0	–
Solar	0+	3	22,2
Biomass, waste, tidal/ wave/ocean	0	0	–
Total Africa	117	212	2,1
Total world	4 428	7 009	1,7

Classification of hydropower plants

Hydropower plants can be classified as large, medium or small, depending on the capacity of power that can potentially be generated. Plants above 500 MW are generally considered large plants. Plants between 500 MW and 10 MW are considered medium-sized plants. Below 10 MW they are considered small-sized hydro plants. Small hydro plants are further classified as mini- (10 MW to 500 kW), micro- (500 to 10 kW) and pico- (less than 10 kW) plants.²⁵

Hydropower in Africa

The hydropower potential in Africa exists in rugged areas. Approximately only 5 per cent of Africa's hydropower potential of more than 1 750 TWh has been exploited. The total hydropower potential for Africa is equivalent to the total combined electricity consumption of France, Germany, the United Kingdom and Italy.²⁶

Hydropower production increased from 28,5 TWh in 1973 to 98,6 TWh in 2008 (approximately 3% of world production).²⁷ Table 1.11 shows hydroelectric indicators in 2007.

Table 1.11 Hydroelectric indicators for Africa in 2007²⁸

Item	Units	History 2007	Projections 2035	Average annual percentage change (2007–2035)
Hydroelectric installed capacity	GW	22,0	42	2,4
Hydroelectric net generation	Billion kWh	97,0	166	1,9
Hydroelectric and other renewable energy consumption	Quadrillion Btu	3,7	–	–

Hydropower large-scale applications

The eastern and southern regions of Africa's have a huge hydro-potential (more than 100 000 MW in the DRC, 45 000 MW in Ethiopia and 6 000 MW in Zambia). The DRC's potential for hydropower, according to the audit of energy resources, Energy Information Centre and the World Energy Council, is by far the highest in Africa, and it also represents one of the highest hydropower potentials in the world.

The Inga River in the DRC holds great potential for hydropower generation in Africa, with an estimated potential of about 40 000 MW. In fact, the DRC alone accounts for more than 50 per cent of Africa's hydropower potential. Other countries with significant hydropower potential are: Angola, Cameroon, Egypt, Ethiopia, Gabon, Madagascar, Mozambique, Niger and Zambia. Despite the low percentage use, large-scale hydropower so far provides more than 50 per cent of total power supply in 23 countries in Africa.²⁹

Hydropower small-scale applications

Small hydropower systems (SHPs – less than 10 MW) can supply energy to remote communities and catalyse developments in such

communities. In environmental terms SHPs are more sustainable than large-scale systems. Most African countries have a large potential for small hydro systems and some are already being exploited, with a special focus on rural communities.³⁰

The eastern and southern regions of Africa have numerous pico-, micro-, mini- and small hydropower sites which can either be developed to supply isolated areas or feed into the national grid. The development of small hydropower plants in these regions should be given high priority, due to their linkages to rural development.

Micro-hydro projects in Africa

There are already some successful micro-hydro projects in Africa – in Kenya, Mozambique, Rwanda and Zimbabwe. The Tungu-kabri micro-hydropower project in Kenya is one such example. The Mbuiru village is a typical Kenyan village; its people are generally poor farmers without access to electricity. Most families spend at least one-third of their incomes on kerosene for light and cooking, or they resort to chopping down trees for firewood. This micro-hydro project was organised by Practical Action East Africa and the Kenyan Ministry of Energy. Villagers worked once a week or more for two years to build it, and it now generates approximately 18 kW of electrical energy, enough to benefit 200 homes.³¹

Africa has many rivers and tributaries that would be suitable for micro-hydro projects. One exciting prospect is the linking together of these micro-hydro projects to create large hydropower projects as a cheap means of energy and a clean energy resource.

Grid-connected hydroelectric installed capacity is projected to increase from 22 to 42 GW from 2007 to 2035, at an average annual rate of 2.4 per cent,³² as shown in Table 1.11.

Biomass Energy

Biomass energy, which refers to a wide range of natural organic fuels such as wood, charcoal, agricultural residues and animal waste, is often used in its traditional unprocessed form. Traditional biomass energy use has serious environmental drawbacks. Africa is the world's largest consumer of biomass energy.

Traditional biomass still remains the source of energy for the majority of the poor. It accounts for 70 to 90 per cent of primary energy supply

in some countries, and as much as 86 per cent of energy consumption. In some countries biomass energy contributes as much as 97 per cent of total energy supply.

Large-scale biomass energy

Large-scale biomass use encompasses direct combustion for process heat; ethanol production; gasification; heat cogeneration; biogas production; and briquetting.³³ The best-known large-scale biomass energy systems with sound economic track records are cogeneration, using biomass as fuel stock and the production of ethanol as a substitute for the petroleum fuel.

Cogeneration is used by agro-based industries to meet their power requirements. Some of the industries involved include the paper and pulp, sugar, wood and rice industries. Sugar is produced in a number of East and Southern African countries. It is a major agricultural export of Ethiopia, Madagascar, Malawi, Mozambique, Swaziland, Zambia and Zimbabwe. The potential for electricity generation from sugar-cane waste (bagasse) is high, since the cogeneration equipment is almost uniformly an integral component of sugar factory designs.

Mauritius, however, demonstrates that more energy can be extracted from biomass fuel using more efficient, state-of-the-art energy conversion technologies. Bagasse used to fire combined-cycle generators now accounts for close to 40 per cent of the island state's electricity generation.³⁴ With regard to clean and more efficient stoves, considerable effort has been put into research & development, and to limit diffusion on a pilot basis in some countries. However, large-scale distribution to the wider population is still a challenge.

Small-scale biomass energy

Viewed in terms of the energy used, small-scale traditional bioenergy systems appear borderline, but their importance lies in the many end-users that these systems serve. Biofuelled cooking-stoves meet the numerous cooking, heating and lighting needs of rural households in Africa.

Charcoal is a main household fuel and, to a lesser extent, industrial fuel. It is mainly used in the urban areas. Traditional charcoal production relies on the traditional and primary earth kiln which is considered to be a major contributor to land degradation in many peri-urban regions of sub-Saharan Africa.

Another small-scale biomass energy technology is biogas. The biogas is produced from cow dung and human excreta. Countries such as Burkina Faso, Ethiopia, Ghana, Kenya, Mali, Niger, Rwanda and Senegal have implemented pilot projects aimed at establishing the technical and socio-economic viability of biogas technology as an alternative energy source for cooking and decentralised rural electrification.

In the case of Ghana, the Appolonia Project installed a system that generates 12,5 kW of electric power³⁵ and supplies electricity at 230 V for 22 houses, street lighting and five social centres in the community.

The majority of sub-Saharan African households rely primarily on wood fuel for cooking and heating. Wood fuel is the main source of fuel in rural areas, whereas charcoal is commonly used in the poorer urban households. As a response to the fuel-wood shortages, improved biomass cooking stoves have been promoted throughout Africa.³⁶ However, the level of adoption has been limited due to many factors such as cost, effectiveness in fuel or cost savings and compatibility with user needs.

Geothermal Energy

Geothermal power is mostly concentrated in eastern Africa, but there are many fragment-spots of high intensity geothermal potential spread across the continent.

'Geothermal energy is the natural heat from the Earth's interior stored in rocks and water within the Earth's crust. The main source of this energy is the constant flow of heat from the Earth's core to the surface. This heat creates the molten rock, or magma, beneath the surface crust. Volcanoes, geysers and fumaroles are the visible evidence of the large reservoir of heat beneath the surface. The magma heats the surrounding rocks and when underground water comes into contact with this heat, geothermal fluid is formed. This energy can be extracted by drilling wells to tap concentrations of steam at high pressures and at depths shallow enough to be economically justifiable. The steam is then led by pipes to drive electricity-generating turbines.'³⁷

Large-scale geothermal energy

Geothermal energy has the potential to generate up to 14 000 MW from geothermal sources. As at October 2011, Kenya has installed up to

127 MW, amounting to approximately 17 per cent of the national power supply, followed by Ethiopia with a 7 MW installation.³⁸ Plans to use the potential of geothermal energy in Eritrea, Tanzania and Uganda are at different stages. Algeria, Egypt and Tunisia currently have projects obtaining geothermal energy for direct heat. In some countries, such as Morocco, the geothermal energy available is suitable for direct heat but not electricity.

However, many countries in Africa have rift valleys with great potential to develop the generation of electricity from this resource. The Eastern Africa Rifts in Mozambique and in Uganda are one of the rift systems that has great potential for future development. Eritrea, Tanzania and Zambia also have geothermal potential that needs to be further investigated and assessed.

Wind Energy

Wind power systems capture the kinetic energy of wind for use as mechanical energy or electricity. Wind turns the blades of a rotor or turbine. This movement rotates a shaft that is connected to a generator, where it is converted into electricity. There are two basic kinds of turbine: vertical and horizontal systems. Horizontal-axis systems are the most commonly seen type of wind power system. They usually have two or three blades that operate upwind (facing into the wind) and can vary in size and use.

Traditional wind turbines are not very big and are used mostly for mechanical energy on farms, usually to pump water, and also for other tasks such as grinding grains. Modern utility wind turbines are much bigger and can generate much more energy.

Wind energy potential is sufficient for electric power generation in coastal regions, and in some interior areas of Africa. Countries with good potential include Cape Verde, Eritrea, Kenya, Madagascar, Mauritania, Morocco, South Africa and Tunisia, as illustrated in Map 1.

Large-scale wind energy

In the beginning of 2008, Africa had approximately 476 MW of installed wind-energy generation capacity compared to the global estimate of 93 900 MW. Countries developing large-scale wind energy projects so far include Egypt, Ethiopia, Morocco, South Africa and Tunisia.

Small-scale wind energy

Owing to low wind speeds, the bulk of wind machines found in eastern and southern Africa are used for water pumping, rather than electricity generation. Wind pumping supplies water for household use, irrigation and livestock. Consequently, some projects have been undertaken in Africa, and there is only limited experience of wind energy in grid connection or mini-grid electricity generation. However, wind pumping and small-scale electricity generation have been developed in many parts of Africa.

Solar Energy

Direct solar energy can broadly be categorised as solar photovoltaic (PV) technologies, which convert the Sun's energy into electrical energy, and as solar thermal technologies, which use the Sun's energy directly for heating, cooking and drying.

The solar thermal electric – or concentrated solar power (CSP) – has a global record of high solar-to-electricity efficiency rates. This technology uses the heat of sunlight to generate electricity and is distinct from PV technology. PV power converts sunlight energy into electricity using PV solar cells. Each PV cell is a small unit that typically produces an amount of 1 to 2 W.

Solar cooking uses the heat of sunlight as a source of energy to cook food. It is low cost and low technology compared to gas, charcoal or burning wood stoves.

Solar energy in Africa

Africa is one of the most sun-rich regions in the world. Many countries have daily radiation levels in the range of 5 to 6 kWh/m².³⁹

Large-scale solar energy

Large-scale solar energy projects are limited in Africa because of cost constraints. Africa has great potential for CSP generation from desert areas such as the Sahara, Namib, etc. Thus far, only South Africa operates a solar thermal power system plant, which generates 0,5 MW. Egypt plans to install a solar thermal plant of 300 MW by 2020. Owing to the large amount of sun energy available in the Sahara Desert, it is the

ideal region for trading energy between North Africa and Europe. Solar power could be exported using high voltage direct current (HVDC) technology.

Small-scale solar energy

Solar energy is used at the household level for lighting, cooking, water heaters and solar architecture houses. Also it is used for water heating in hotels and irrigation. At the community level, solar energy is used for vaccine refrigeration, water pumping, purification and rural electrification. At the industrial level, solar energy is used for pre-heating boiler water for industrial use, power generation, municipal water heating, telecommunications and transportation.

South Africa and Kenya have the highest documented installed capacities of solar PV systems in Africa. They represent more than 11 000 and 3 600 kWp, respectively.⁴⁰

Nuclear Energy in Africa

Nuclear energy is a realistic option for further production of electricity in Africa. The country's first commercial nuclear power reactor began operating in 1984.⁴¹ South Africa has two nuclear reactors generating 5 per cent of its electricity. The South African government plans to have another 4 GW of nuclear capacity online by mid-2018.

Tables 1.12 and 1.13 represent the installation and the net nuclear generation for Africa, respectively. These figures assume that South Africa will complete the construction of the reactors it has planned. The nuclear share of the region's total power generation will have increased to 3 per cent in 2035.

Table 1.12 Installed nuclear generating capacity (GW)⁴²

Region	History 2007	Projections 2035	Average annual percentage change (2007–2035)
Africa	2	4	3,0
World	380	593	1,6
	0,53%	0,68%	

Table 1.13 Net nuclear electricity generation (billion kWh)⁴³

Region	History 2007	Projections 2035	Average annual percentage change (2007–2035)
Africa	12	31	3,5
World	2 593	4 514	2,0
	0,46%	0,67%	

Conclusion

The African continent is endowed with tremendous untapped renewable energy resources, including hydro, solar, wind, biomass and geothermal, which could be used to produce a large percentage of the electricity that Africa needs. Primary energy production, supply and consumption in Africa have been growing rapidly since 1973. This chapter provided an overview of energy in Africa, starting by presenting statistics on energy evolution during the period 1973 to 2008/2009 for each type of energy status of Africa and different energy resources, emphasising renewable energy. The rapid increase in world energy prices from 2003 to 2008, combined with concerns about the environmental consequences of GHG emissions, has led to a renewed interest in the alternatives to fossil fuels. The developing countries of Africa have common locations for the implementation of renewable energy technologies. At present, many countries already have small-scale solar, hydropower, wind, and geothermal devices in operation that provide energy to urban and rural populations. Lastly, the chapter provided an overview of renewable energy technologies as drivers of Africa's energy supply.

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Africa's nuclear power potential

Its rise, recession, opportunities and constraints

Mojalefa Murphy

Introduction

Africa's lack of capacity to benefit from its vast uranium resources is usually attributed to regional poverty and the fact that providing nuclear power is extremely expensive.¹ However, a closer examination of Africa's human development reveals considerable social and economic dynamics that relentlessly undermine the scientific and technological advances needed to derive benefit from natural resources. Moreover, between 2005 and 2009, an estimated \$564 million was jointly received by the governments of Niger and Namibia from uranium mining in income tax, royalties, shares and selling rights.² Therefore, more explanation is needed for regional failure to tap the abundant nuclear power potential than the hitherto convenient assumption of poverty.

This chapter explores some of the historical and contemporary factors which explain Africa's underdevelopment, in general, and the constraints upon any effort to develop an indigenous capacity to realise the regional nuclear power potential, in particular.

The growth of African uranium mining and related nuclear industrial developments may be traced back to the 1915 discovery of uranium ores in the then Belgian Congo, and the involvement of South African scientists in early European investigations of radioactivity in the 1920s.³ During this period, African uranium was exported to Europe for the production of radium, which fetched as much as \$75 000 per ounce and

was used in the radiation management of cancer.⁴ The regional nuclear industrial capability, the development of which started in essence in the mid-twentieth century in South Africa, reached its peak in the mid-1990s, when a nearly complete nuclear fuel cycle was operational. In addition to the indigenous nuclear fuel production and generation of electricity, about six nuclear warheads had been manufactured before the decline of the industry. Whereas the nuclear industry reached its peak, uranium mining has continued to grow under almost identical social and economic conditions. This chapter attempts to explain this apparent contradiction in the context of the conflicting interests of the aggressors – proponents of colonialism, apartheid, neocolonialism and neo-apartheid, on the one hand, and those of the vast majority of the subjugated African people, on the other. This is achieved through a detailed examination of the historical events that contributed to Africa's uranium mining and nuclear industrial developments in the Belgian Congo and South Africa.

The role of nuclear energy is a controversial subject despite the enormous impact its peaceful and responsible uses have had over a period of more than a century. This controversy appears to be sustained by global concerns about the destructive potential of nuclear industrial accidents, the challenges that arise from the management of the highly toxic radioactive nuclear waste, and proliferation of the related technology for production of weapons of mass destruction.⁵ The controversy is also fuelled by the negative perceptions linked to the secret manner in which business is traditionally conducted in an industry that is bound to uphold high levels of security and safety standards. These negative perceptions and the link to secrecy tend to overshadow the peaceful and responsible applications, which would not only be cost ineffective but also economically unsustainable, if nuclear power were taken out of the equation. The lack of awareness of nuclear technology and its associated risk impact on social and economic development contributes to the negative perceptions. However, national authorities with a sound understanding of the strategic importance of maintaining their nation's technological edge continue to invest in their nuclear enterprises.

The development of a nuclear power capability has been traditionally pursued under a veil of secrecy, often disregarding the voice of the electorate. This is despite the fact that the collateral impact on the environment and long-term management of the resultant nuclear radioactive waste is an inevitable burden for all citizens and future generations, and thus a matter of immense public interest.

Consequently, nuclear affairs ought to be administered in an open and transparent manner that would enable the citizenry to hold the authorities accountable. In particular, the African citizenry has a responsibility to participate meaningfully in any quest for industrial capability to harness nuclear power in the twenty-first century. It is therefore necessary to raise scientific and technological consciousness among the scientifically silent African majority, objectively and independently of industrial public relations stunts and the antagonistic campaigns of social interest groups. To give context to this chapter, an introduction to the basic concepts of nuclear science and technology applicable to nuclear energy is included. This introduction also aims to explain the value of nuclear technology, its benefits to human development and its impact on the shaping of Africa.

Basic Science and Technology of Nuclear Power

In science, knowledge of the structure and interaction of matter underpins the dynamic quest for the understanding of nature. This fundamental understanding is crucial to the development and exploitation of technology in order to solve problems of societies such as health. It is convenient for scientists to view matter as an assembly of minute building blocks referred to as 'atoms'. An atom is an assembly of a very small positively charged nuclear mass that is surrounded by a cloud of orbiting electrons or negative electric charges, very much like the solar system.

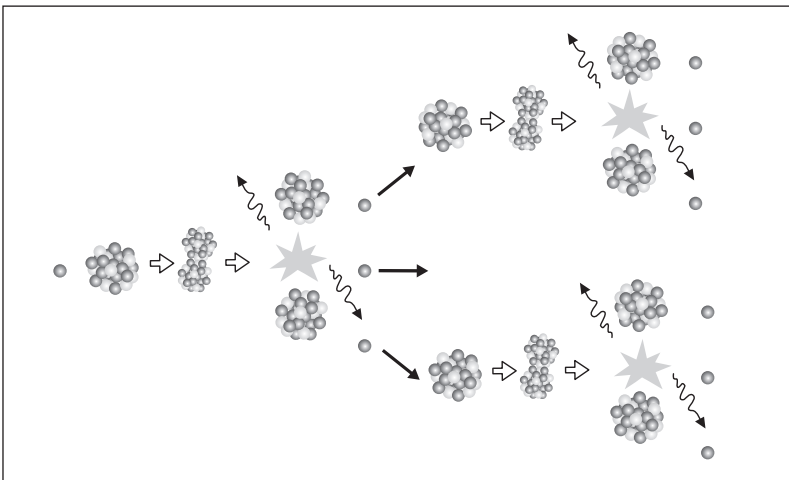
Nuclear scientists are interested in the atomic nucleus, which is made up of protons, that is, positive electric charges, and neutrons that are electrically neutral. Since the protons are like charges which repel each other, the nucleus is held together by the stronger nuclear forces rather than the repulsive electric ones.⁶ The number of protons in a nucleus defines the identity of the element of matter.⁷ Thus the simplest nucleus with one proton defines hydrogen. When the number of nuclear neutrons differs from one atom to the other, the atomic nuclei are referred to as 'isotopes'.⁸ Thus, hydrogen has three naturally occurring isotopes: a protium, denoted ${}^1\text{H}$, with no neutrons; deuterium (${}^2\text{H}$), with one neutron; and tritium (${}^3\text{H}$), with two neutrons. When the latter two hydrogen isotopes combine with oxygen chemically, the resulting compound is regarded as 'heavy water'.⁹ Uranium, with 92 nuclear protons, on the other hand, occurs naturally as a composite of mainly three isotopes, namely, ${}^{238}\text{U}$ with 146 neutrons, ${}^{234}\text{U}$ with 142 neutrons and ${}^{235}\text{U}$

with 143 neutrons. The atoms or nuclei with disproportionately many neutrons such as uranium are regarded as being neutron rich.

The splitting or fission of a heavy neutron rich nucleus is one nuclear reaction that results from the absorption of a loose neutron. As an example, when a nucleus of a fissile elemental isotope such as ^{235}U absorbs a free neutron, it forms an even heavier and unstable nucleus of ^{236}U that fissions into two nuclear fragments of ^{89}Kr and ^{144}Ba , which possess high energy of movement. During this fission reaction, more free neutrons and electromagnetic radiation, which accounts for only approximately 3 per cent of the total energy released, are produced. These neutrons further interact with other fissile nuclei, causing a chain reaction of nuclear fission. The balance of approximately 97 per cent of the fission energy results from the kinetic energy of the fission fragments which fly apart as a result of electrostatic force that take effect between like charges of the protons of the splitting nuclei. The fragments travel at 3 per cent of the speed of light – in excess of 320 million kilometres per hour.

The total energy released during a fission reaction of each fissile uranium isotope is nearly 200 MeV, which is 200 million times the kinetic energy of an electron that is travelling towards a positive of 1 V. By way of comparison, the amounts of energy contained in a nuclear fuel element are more than 10 million times the energy contained in the same mass of combustible

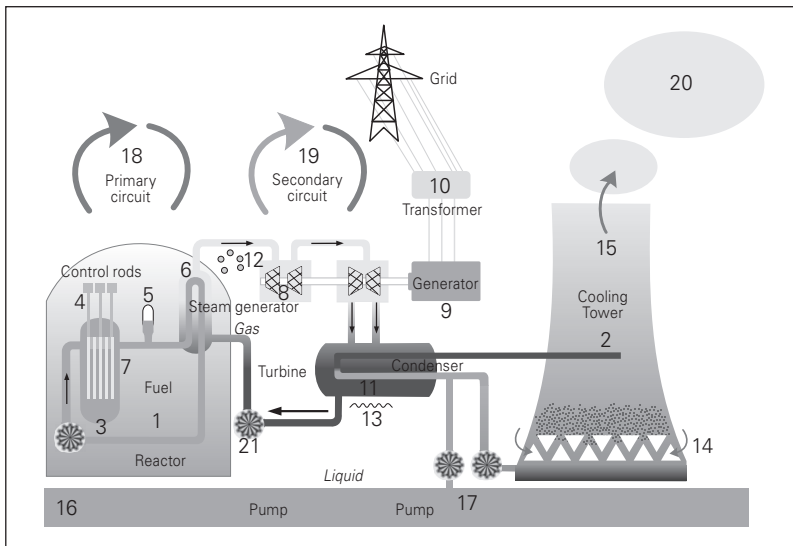
Figure 2.1 A ^{235}U fission chain reactions illustrating energy released in the form of kinetic energy of the fission fragments and radiation



chemicals such as trinitrotoluene (TNT) and coal. Consequently, it takes very little nuclear fuel to produce huge amounts of energy and tiny volumes of waste, as compared to conventional chemical processes.

The kinetic energy of the fission fragments is converted to heat as they continuously collide with components of a nuclear reactor containing fuel. The chain reaction in a nuclear reactor is controlled by the insertion of neutron-absorbing materials such as boron into the core of the reactor containing fabricated nuclear fuel elements made of fissile uranium.¹⁰ This control entails starting up the chain reaction by removing the boron control rods and completely shutting it down by fully inserting them into the reactor among the ^{235}U fuel rods. The process is referred to as ‘boron moderation of the chain reaction’. Light water, $^1\text{H}_2\text{O}$, is used to cool down the reactor by taking away the heat that results from the released kinetic energy of fission fragments in the reactor core. This is achieved by the reticulation of the cooling water through a primary circuit that passes across the heat exchanger of the steam generator, which are components of the secondary circuit as illustrated in Figure 2.2. The steam produced in the heat exchanger is injected into the turbines, which rotate to generate electricity.

Figure 2.2 Nuclear-steam power station: A schematic illustration showing key components for the provision of nuclear-generated electricity¹¹



Nuclear fuel cycle and uranium enrichment

The abundance of the fissile isotope ^{235}U in natural uranium, in which the non-fissile ^{238}U accounts for more than 99 per cent, is less than 1 per cent.¹² This rare abundance necessitates the isolation or separation of the fissile uranium isotope in order to increase its concentration by a significant amount for the manufacture of nuclear fuel. The separation of the ^{235}U , or simply uranium enrichment, is one of a series of about nine core industrial activities that are collectively referred to as the 'nuclear fuel cycle'. A widely used enrichment process is the gas centrifuge separation, which exploits the slight difference in the masses of ^{235}U and ^{238}U . In this process the feed, UF_6 , is rotated in a cylinder which collects the gas molecules containing the lighter and heavier uranium isotopes, respectively, against its wall and in the centre. The centrifuges are arranged in series and parallel, enabling the output of one unit in the cascade to serve as input to the next one until the target level of enrichment – typically 3 to 5 per cent ^{235}U composition for power generation – is achieved.

When nuclear fuel is enriched to low levels for use in power reactors, it is referred to as 'lowly enriched uranium' (LEU). Higher levels of enrichment yield 'highly enriched uranium' (HEU). It takes several years of uranium enrichment to produce weapons grade HEU using the cascaded centrifuge method of isotope separation.¹³

There are other methods of uranium enrichment, some of which have found earlier application in industry. Others have been tried successfully in experimental laboratories.¹⁴ The former is chiefly the gaseous diffusion method which exploits the difference in the molecular velocities between $^{135}\text{UF}_6$ and $^{138}\text{UF}_6$ to separate them by passing the UF_6 gas through porous barriers or membranes. The fissile isotopic gas, $^{135}\text{UF}_6$, passes through the membrane more rapidly than $^{138}\text{UF}_6$.

Laser uranium enrichment techniques, namely, molecular laser isotope separation (MLIS) and atomic vapour laser isotope separation (AVLIS), are the main enrichment methods. They exploit the difference in the atomic composition of ^{135}U and ^{138}U in uranium, which makes them absorb light differently, in order to excite the former and eject it from the mix. These laser-based methods, which respectively use UF_6 and vapourised uranium atoms as feedstock, have yet to be industrialised. The industrial provision of nuclear fuel from the mined uranium ore constitutes the front end of the nuclear fuel cycle, depicted in Figure 2.3. Step 1 involves the mining, milling and leaching of the uranium to extract a mixture of the metallic oxides, mainly triuranium octoxide

(U_3O_8) of typical 80 per cent composition, uranium trioxide (UO_3) and uranium dioxide (UO_2). This powdery mixture of metallic oxides also referred to as 'yellow cake', is as dense as sulphur and much lighter than the ore. Yellow cake is then chemically converted to a gaseous uranium hexafluoride (UF_6) (in step 2), which is a conventional feed for the next industrial process of uranium enrichment in the cycle (in step 3). The fabrication of nuclear fuel bundles from the pellets made of LEU, which is a reconvention of the enriched gaseous UF_6 to a metallic UO_2 , is then achieved (in step 4).

The end of the nuclear fuel cycle begins with the fabrication of nuclear fuel, as depicted in step 4, and ends with its ultimate disposal indicated in step 9.

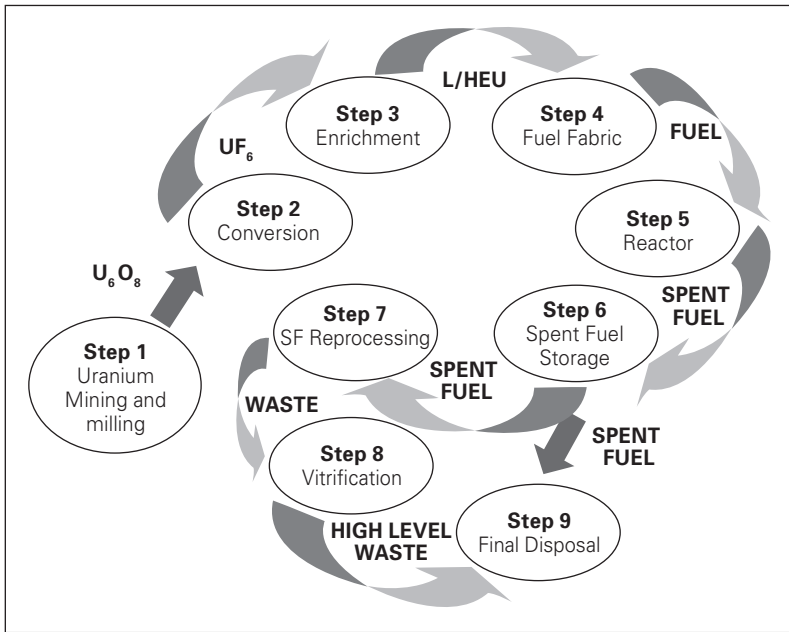
The production of radioactive isotopes or, more accurately radionuclides, the irradiation of food for its preservation, and the provision as well as the use of radiopharmaceuticals in nuclear medicine constitute part of the end of the nuclear fuel cycle. The intermediary industrial processes that are used or spent fuel undergoes before disposal include temporary storage (step 6), reprocessing (step 7), and recycling (step 8).

Naturally occurring uranium may also be used as fuel in a reactor to produce nuclear energy, as in the Canadian-developed heavy water moderated reactor, Canada Deuterium Uranium (CANDU). This type of reactor may also be used to produce tritium, 3H_2O , as a by-product that results from the capture of fission neutrons by a moderator, 1H_2O . Tritium is used as a neutron source in nuclear warheads to start the uranium fission chain reaction.

The Uses of Nuclear Energy

Nuclear medicine

Following the discovery of radioactivity in 1896, the radiation component of nuclear energy was mainly applied in medical imaging and subsequently provided the foundations of the modern brachytherapy¹⁵ or Curie-therapy and diagnostic nuclear medicine.¹⁶ Brachytherapy exploits the natural susceptibility of actively dividing biological cells to radiation damage. In nuclear medicine, radioactivity emitted by ingested radionuclides or radiopharmaceuticals is detected and diagnostic images constructed to examine the targeted organ function of patients.¹⁷ ^{99}Tc is one form of several of the radioisotopes of the atomic nucleus of Technetium, which is used widely in nuclear medicine.

Figure 2.3 The nuclear fuel cycle for non-military applications

Food, agriculture and the environment

Radioactivity in agriculture and food security finds application in the provision of crops that are disease- and weather-resistant, improved reproductive capacity of animals and extended shelf life of food, particularly spices and army supplies. Furthermore, radioactivity is also used routinely in water resource management and environmental quality maintenance. It is also used in a wide variety of scientific studies, including Biochemistry and Genetics in which physiological processes involved in the production and transport of amino acids and deoxyribonucleic acid (DNA) are investigated using radioactivity-tracing techniques.

Carbo-dating techniques

The techniques of carbon dating which exploit the exponential decay of the strength of radioactivity of the carbon radioisotope, ^{14}C , also find application in Geology, Archaeology, Palaeontology and Forensic Science.

Other non-power uses

In manufacturing and mining, radionuclides are used to inspect the quality of welds and minerals, respectively; to determine the rate of erosion and corrosion of metals and to detect leaks. Residential, commercial and industrial fire prevention and safety systems rely on the use of radioactive americium to trigger early-warning signals of the presence of smoke from fire.

Nuclear power

The uses of nuclear energy in the form of electromagnetic radiation or radioactivity had been purely peaceful for some 48 years from its discovery, until the US dropped two atomic bombs on Hiroshima and Nagasaki in 1944. This military use of nuclear energy became possible only after the discovery of a neutron in 1932 and subsequent fission reaction in 1938 in England and Europe, respectively. The peaceful use of nuclear kinetic energy or nuclear power was subsequently achieved in 1954. This followed the world's first nuclear power generation of about 5 MW in the former Union of Soviet Socialist Republics (USSR) for transmission through a grid to the town of Obninsk.

The Organisation for Economic Cooperation and Development (OECD) estimates that in addition to identified world uranium resources, there is about twice as much that has yet to be discovered. Assuming the 2002 rates of uranium consumption, these reserves correspond to about a 270-year supply for the world's nuclear fuel needs. Through further uranium extraction from seawater and the use of fast-breeder reactors to yield fissile plutonium by way of recycling conventional uranium fuel, further tens of thousands of years' supply of fuel could be realised.¹⁸ Therefore, despite the current concern regarding the safety of nuclear technology and materials, the storage of radioactive waste and fears of nuclear weapons proliferation, nuclear energy will inevitably play an increasing role as part of the mix to fuel the world economy in the twenty-first century.

Africa's Potential to Exploit Nuclear Power

Africa's potential to harness nuclear power for human development in the twenty-first century is assured by the abundance of its uranium deposits and affordable human resources. However, this potential is

undermined by the unabated lack of critical mass of the requisite nuclear scientific expertise, primarily due to the persistent neocolonial tradition of depriving the majority of the African people of the opportunity to participate meaningfully and benefit from the contemporary scientific and technological advances.

The 1915 discovery of the Shinkolobwe high-grade uranium deposits in the then Belgian colony of the Congo took place more than two decades before the science and technology to harness nuclear power were developed, early in 1938. This discovery was the first indication of Africa's potential to gain from the beneficiation of uranium that would later include the provision of nuclear electricity. In his 1939 letter to President Dwight Eisenhower, alerting him to the imminent construction of atomic bombs by the Germans on the basis of nuclear research work carried out by Enrico Fermi in the US, Albert Einstein wrote: 'The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is Belgian Congo.' The Congolese uranium was subsequently mined and mostly exported to the US, as much for the economic benefit of Belgium as for the use in the Manhattan Project that led to the construction of the atomic bombs that were detonated in Japan. In gratitude for the supply of high-grade uranium that made the bombings on Japan possible, the US provided the Belgian Congo with Africa's first 50 kW research nuclear reactor, TRIGA I, in 1958 under the aegis of President Dwight Eisenhower's Atoms for Peace programme.¹⁹ The acronym reveals the purpose of the programme: **T**raining, **R**esearch and **I**sotope production and built by **G**eneral **A**tomic, which was to increase the potential for nuclear power exploitation on the continent. However, when Belgium granted the Congo independence and handed power to its first African Prime Minister, Patrice Lumumba, in 1960, the Shinkolobwe operations were decommissioned, and the mine shafts deliberately flooded with water and sealed with concrete.

Twelve years after Lumumba was deposed in a coup d'état led by Mobutu Sese Seko with the aid of Belgium and the Central Intelligence Agency (CIA), the US commissioned TRIGA II. The reactor was made in support of the nuclear research activities at the Kinshasa University campus under the auspices of the Regional Centre for Nuclear Studies that was established by the Organization of African Unity (OAU) in 1967. In addition to the DRC's TRIGA II, which is temporarily out of commission, some nine other research reactors operate in Africa and

provide the support for the requisite nuclear science and technology education, training and research for potential application in the provision of nuclear power. According to the International Atomic Energy Agency's (IAEA's) count, these reactors are in Algeria (2), Egypt (2), Ghana, Libya, Morocco, Nigeria and South Africa.

The educational and scientific foundations for the exploitation of nuclear power were laid down in the nineteenth and twentieth centuries when the colonised African communities were preoccupied with the struggle to resist the appropriation and pillage of their land through the exploitation of their labour. They were subjected to a colonial education system that was designed to either assimilate or adapt them for limited and localised social service for the advancement of the invasive agenda of the European colonialists. This education was also designed to forestall any tendency to challenge the state, while entrenching the dependency of the Africans on the metropole. In particular, they were systematically excluded from any scientific and technological developments of strategic importance to the state of the colonial powers. Consequently, direct colonial domination was ended, only to give way to a new era that continued to be characterised by the lack of a significant scientific and technological culture among the African communities, let alone any capacity for whole communities to take up advanced expertise and exploit its benefits.

Owing to its dual use in clean power generation and nuclear weaponry, uranium has been a strategic resource for the world nuclear powers since the middle of the twentieth century. The urgency of the need to reduce carbon emissions in a globally recognised effort to militate against global warming has extended the strategic importance of uranium and nuclear energy technology to the rest of the world in a quest to reduce dependency on hydrocarbon energy sources in the twenty-first century. As a result, Africa, which currently accounts for some 22 per cent of the world's uranium supply, is experiencing an unprecedented influx of prospecting and exploring fortune hunters from Australia, Canada, Europe (including France and the United Kingdom) and other nuclear power countries such as China, Russia, South Korea and the United States.

Table 2.1 illustrates the distribution of the current involvement of foreign-power-based mining companies in the prospecting and/or exploration of uranium in some of the African countries with deposits. With the exception of South Africa and Zimbabwe, none of the operating companies is wholly African owned. This is regardless of the fact that despite the large uranium supply, Africa only produces a mere

Table 2.1 Distribution of prospecting and exploration companies from nuclear power countries currently operating in Africa

Uranium reserves location	% world electricity consumption ²¹	Origin of uranium prospecting and exploration companies ²²				
		Australia	Canada	France	UK	Others
Angola	0,015	√				√
Botswana	0,013	√				
Burkina Faso	0,003		√			
Burundi	0,001	√	√			√
Cameroon	0,023	√			√	
CAR	0,0005	√				√
Chad	0,502	√	√	√	√	√
DRC	0,004			√	√	√
Egypt	0,002			√		√
Gabon	0,007					√
Guinea	0,004	√				
Libya	0,107					
Madagascar	0,004		√	√	√	√
Malawi	0,008	√				
Mali	0,002	√				
Mozambique	0,049	√	√		√	√
Namibia	0,014	√	√		√	√
Niger	0,003	√	√		√	√
South Africa*	1,037		√	√	√	√
Tanzania	0,015	√	√		√	√
Zambia	0,043	√	√			√
Zimbabwe*	0,052					

* Countries with wholly African-owned companies.

0,5 per cent of the world nuclear power in the form of 1 800 MW generated by the sole power station in South Africa.²⁰ Moreover, the entire African community uses a mere 2 per cent of total world electricity consumption, more than half of which is consumed in South Africa.

Despite the DRC having Africa's first nuclear reactor, the Congolese people rank among many communities with the lowest energy consumption: it accounts for only 0,002 per cent of the world total. South Africa, on the other hand, produces and consumes more than 50 per cent of Africa's total, with all the regional nuclear power production amounting to approximately 0,5 per cent of the world nuclear power total. However,

the development of the nuclear enterprises in South Africa and the DRC occurred under similar political–historical circumstances of active racial exclusion from any meaningful participation in the mainstream of the related scientific and technological activities. These extremities and similarities of South Africa and the DRC may provide valuable lessons from which the rest of African communities with uranium resources may benefit in any attempt to develop their own nuclear capacity. Since South Africa developed an almost complete nuclear fuel cycle before the demise of apartheid, a detailed overview of the underlying political–historical dynamics of this development may elucidate the severity of the constraints that the DRC experienced and, by extension, to which the realisation of the African nuclear power potential is subjected.

Nuclear Industrial Development in South Africa: 1950 to 1970

South African scientists appear to have been involved in the early radiation scientific studies,²³ particularly in the detection and measurement of neutrons as early as 1945.²⁴ By the same year, a Uranium Committee, chaired by Dr Basil Schonland, had been formed in response to Prime Minister Jan Smuts' order for the exploration of uranium deposits on behalf of the British government.²⁵ Following the discovery of large deposits of uranium, the Atomic Energy Board (AEB) was established on the basis of the Atomic Energy Act 35 of 1948.²⁶

In 1957 South Africa and the US signed a 50-year bilateral agreement under the auspices of Atoms for Peace. South Africa gained immense benefit from nuclear expertise transfer over the following years. This included the acquisition and commissioning of the SAFARI I research nuclear reactor in 1965 and training of some 90 scientists, engineers and technicians. Between 1953 and 1965 more than 40 000 tons of uranium oxide worth \$450 million was exported.²⁷

By 1964, South Africa was technologically well positioned to exploit the US-sponsored programme of peaceful nuclear explosives (PNE) for mining and earth-moving activities, for example in the construction of harbours. The neutron beam provided by the SAFARI I for nuclear R&D was complemented by accelerator-based production of charged particles. In particular, Cockcroft-Walton generators and a 16-million electron volt (MeV) cyclotron to provide deuteron beams were made operational at Pretoria University by 1955 and at the University of the Witwatersrand and Potchefstroom University by 1960. These nuclear

technological installations, together with various electronic measuring instruments, equipped tertiary education and research facilities for the development of advanced scientific skills and the provision of supportive R&D for the growing nuclear industry.

The main AEB mission of uranium enrichment for the production of nuclear fuel and possibly weapon-grade HEU, required more highly specialised scientific skills and research support than the training capacity at all the major South African universities of Pretoria, Potchefstroom, Witwatersrand, Cape Town and Stellenbosch combined and the Council for Scientific and Industrial Research (CSIR) could possibly provide. Consequently, the cyclotron and the Van de Graaff accelerators were commissioned one after the other at the CSIR campus in 1963, the AEB's Pelindaba site and Faure in 1964.²⁸ The design of the Van de Graaff accelerators suggests every intention to provide neutron beams for use in the determination of the so-called 'nuclear reaction cross sections' or the estimates of the probability that nuclear reactions such as fission would occur under certain conditions.

In 1967, a heavy water moderated nuclear reactor that used slightly enriched uranium and was code-named SAFARI II, was constructed in parallel with the development of a uranium enrichment plant.²⁹ The uranium enrichment plant could provide LEU to fuel nuclear power reactors for electricity generation, and HEU to equip nuclear bombs. SAFARI II could be used to generate electricity and/or produce tritium as a source of neutrons inside a nuclear warhead for its detonation. The two major technology development initiatives competed for the limited project resources, notably the financial and the requisite scientific and technical human resources.

Ratcheted Up Nuclear Industrialisation and Weapons Development: 1970 to mid-1980s

Between early 1970 and 1989, the nuclear industrial pursuits were ramped up after SAFARI II development was abandoned in favour of the uranium enrichment project. In an apparent response to the increasing international isolation because of apartheid, the Vorster regime adopted a strategy of developing energy self-sufficiency to fuel the South African war machine and industry. Neatly intertwined with this strategy was the policy of establishing regional military superiority in order to maintain total dominance. In terms of the apartheid strategy, domestically available coal was earmarked for conversion to petrol and diesel to offset the

impact of the international oil embargo of South Africa. Consequently, the coal-to-petrol/diesel conversion technology that was first employed at Sasol in 1955 was developed a step further to increase the capacity for production of synthetic fuels at Secunda's Sasol II and III, beginning in 1979 and 1984, respectively. This technology was also adapted for the conversion of natural gas that was discovered off the coast of Mossel Bay in 1984 in order to further decrease dependence on foreign sources.

The diversion of coal and gas to Sasol for the production of synthetic fuels necessitated the commercial procurement of nuclear reactors for the generation of electricity to substitute the conventional chemical process. The construction of the Koeberg nuclear power station was commenced in 1976 to house the two French-procured, pressurised-water nuclear reactors that became operational in 1984 and 1985.

In 1974 a uranium enrichment plant, codenamed Y-Plant, was commissioned at Pelindaba. The plant achieved a full-cascaded operation in 1977, providing weapon-grade HEU for the manufacture of the first prototype of a nuclear-armed warhead – reportedly by the Armaments Corporation of South Africa (Armcor). This was one of several critical milestones towards attaining the goal of energy self-sufficiency and regional military dominance. The Y-Plant used the domestically developed aerodynamic enrichment process, which employed a curved nozzle or stationary centrifuge and a mixture of uranium hexafluoride and helium or hydrogen gases to achieve the requisite high-flow velocities as a feed. Although the South African aerodynamic separation process bore some resemblance to Germany's Becker nozzle process, it differed from it significantly in that it used a compressed gas mixture at much higher pressure than was used in the latter method.³⁰

The construction of the nuclear fuel manufacturing plant code-named BEVA and the installation of the zirconium tubing workshop and the high-temperature and pressure fuel test facilities, among others, appear to have been part of the French nuclear energy technology transfer package.³¹ This technology transfer occurred at the height of the international arms embargo against apartheid embodied in the 1977 United Nations Security Council Resolution 418, which made the military embargo mandatory.³²

The escalation of the guerrilla wars for the liberation of Mozambique and Angola from Portuguese colonialism occurred in parallel with increasing South African regional and internal security concerns, which appear to have spurred its decision to embark on a nuclear weaponry programme. By 1972 South Africa had thrown its weight fully behind

the Estado Novo authoritarian regime in Portugal, supporting its colonial armed forces against the freedom fighters in the former Portuguese colonies of Mozambique and Angola.³³ In an apparent preparation to retaliate against the increasing Cuban and Soviet Union's support for the liberation movement in the region, Prime Minister BJ Vorster authorised the development of thermonuclear weapons as well as gun-type and implosion fission nuclear bombs in 1974. This decision followed the reported defence agreement that the Israeli Minister of Defence Shimon Peres and Vorster signed during a secret meeting held in Geneva that year. Israel had apparently pledged to furnish South Africa with eight medium-range, surface-to-surface ballistic missiles codenamed 'Jericho II' capable of delivering a 22 000 kg payload as far as 1 400 km, armed with unspecified warheads under a subsequent amendment of this agreement.³⁴

These developments followed the 1972 commissioned studies to separate lithium isotopes ^7Li at AEB's Pelindaba site, for the possible provision of tritium to boost fission of nuclear weapons. They also followed the 1972 commissioning of the development of mechanical and pyrotechnic components for a gun-type nuclear device at Somchem's propulsion laboratory in Somerset West, Cape Province.³⁵ These components are used to slam two subcritical pieces of HEU together to achieve an explosive fission chain reaction. The departure from the 1971 commissioned PNE initiative was made in 1974, the same year the Estado Novo rule was overthrown by the left-wing Portuguese military officers. It is important to note that the Estado Novo coup d'état had paved the way for the independence of Mozambique and Angola in 1975. South Africa backed the friendlier right-wing National Union for the Total Independence of Angola (UNITA) and Mozambican National Resistance (RENAMO) political movements that vied for power against the People's Movement for the Liberation of Angola – Labour Party (MPLA) and the Liberation Front of Mozambique (FRELIMO) in Angola and Mozambique, respectively. The latter progressive and Soviet–Cuban-backed liberation movements supported the struggle to end apartheid led by the African National Congress (ANC).³⁶

It would appear that by 1977, a year after the US Carter administration severed nuclear cooperation with South Africa, the country was ready to test a nuclear bomb. But after the Soviet Union spy satellite, Cosmos 922, detected the completed Vastrap test facility in the Kalahari Desert, the tests did not take place.³⁷ The following year, a US satellite detected a flash resembling a low-yield test of a nuclear explosion in

the South Atlantic off the South African coast, which has since sparked speculation about the involvement of the South Africans. By 1979 the Y-Plant was able to produce at least 50 kg of weapon-grade HEU to construct one gun-type nuclear bomb per year. This is the same year that the AEB transferred the nuclear weapons programme to Armscor for further development of the gun-type bomb. The corporation was formed in 1968 in response to the United Nations sanctions that had been ratified the previous year.

In 1981, Armscor commissioned an unmarked building for the nuclear weapons development deep inside the borders of its facilities at Kentron Circle, later renamed Advena, about 20 km west of Pretoria. By 1985, seven gun-type nuclear warheads had been produced after the successful completion of the first whole assembly by the Atomic Energy Corporation (AEC), the successor of AEB in 1982.³⁸ Despite this achievement, the nuclear weaponry capability was not fully accomplished, primarily because it was abandoned following the unsuccessful quest for a suitable weapons delivery system; subsequently De Klerk announced the imminent implosion of apartheid in 1990.³⁹

It would appear that the surface-to-surface missile systems available at the time would not be suitable to launch the South African nuclear bomb, due to the inherent danger arising from having subcritical quantities of fissile material confined in a shape that could easily form a critical mass, thus increasing the chances of an unintended fission chain reaction occurring without any control.⁴⁰ Moreover, any air-to-surface delivery was not possible because the only aircraft that was suitable for the low strike, the Buccaneer S Mk 50, was vulnerable to the advanced air defence systems to which their Soviet-Cuban-backed adversaries had access.⁴¹

Rapid Nuclear De-industrialisation: Mid-1980s to Date

After the failure of her armed intervention in an attempt to prevent the establishment of hostile black governments in Angola and Mozambique during the 1975–1976 civil wars, South Africa redirected her resources that were constrained by the international economic sanctions to address her conventional military shortcomings.⁴² It became apparent that, in addition to being unable to break the air defences of their Cuban- and Soviet-backed adversaries, who were equipped with the technologically advanced surface-to-air missiles 9K33 OSA and 9K31 Strela-1, the

South African Defence Force (SADF) was outnumbered in terms of the deployed tanks and fighter aircraft. Moreover, their aircraft were ageing and spare parts were difficult to import due to the international sanctions against apartheid. It then became necessary to build a domestic conventional arms industrial capability to reduce dependency on foreign supplies. Furthermore, a chemical and biological warfare development programme was established in the early 1980s under the aegis of the SADF, including the production of lethal and non-lethal chemical reagents to load grenades and mortar bombs.

The 1980 fall of Rhodesia – the main ally to the north – further undermined South Africa's security. With the momentum of the liberation struggle increasing inside and outside South Africa in a manner that severely undermined economic growth, the weakened SADF was reduced to gangs of marauding commandos that terrorised the communities of neighbouring countries in a purported search for armed freedom fighters, notably the members of ANC's Mkhonto we Sizwe. These raids were carried out with disastrous consequences, such as was the case with the December 1982 Maseru massacre of 42 unarmed Basotho and South African exiles living in Lesotho.⁴³ The ANC immediately retaliated by bombing the first unit of Koeberg nuclear power station that was under construction towards the end of December 1982, causing a reported \$1.8 billion in damages.⁴⁴

The strategic refocusing on the development of conventional arms capability and the major technical challenges of rendering the prototype of the gun-type nuclear weapon deliverable coincided with increasing international sanctions which slowed down South Africa's economic growth during the mid-1980s. Therefore any further nuclear weaponry development programme was curtailed significantly by a combination of extreme resource constraints and the mandatory UN arms embargo, which also prohibited any nuclear dealings with South Africa. Although the number of nuclear warheads could be increased steadily, South Africa could not render them deliverable, despite the reported military links with Israel specifically for missile and nuclear weaponry development and the reinstatement of nuclear cooperation with the US by the Reagan administration, which approved the sale of computers that could have been used to advance the nuclear weapons programme.

While the highly secret nuclear weaponry programme could no longer be pursued to its intended conclusion, it appears to have played an important diplomatic role in executing the deceitful nuclear deterrent strategy. This policy also appears to have doubled as a face-saving

exit strategy from the failed attempt at building a deliverable nuclear weapon to attain the defeated Afrikaner goal of regional white-minority dominance in the sub-continent. Furthermore, the strategy sought to fully exploit the international outcry against the much exaggerated nuclear warfare capability, following the discovery of the underground explosive test facility Vastrap in the Kalahari Desert, and the reported detection of a flash from a suspected nuclear weapon test in the South Atlantic off the South African coast.

In terms of this strategy:

- The possession of nuclear weapons by South Africa would be kept secret if there were no invasive hostilities.
- Nuclear capability would be indicated to major powers when South Africa was threatened; alternatively it would be declared publicly.
- A nuclear bomb would then be detonated underground or tested in an open ocean test.
- As a last resort, South Africa would threaten to use its nuclear capability on the battlefield.⁴⁵

This nuclear deterrent strategy was revealed well after the Afrikaner elite stunned the world by surrendering power meekly to the African majority in 1990.

The significance of De Klerk's announcement of the unbanning of the liberation organisations, the release of the political prisoners and the return of exiles, and the dismantling of the nuclear weapons successively in February 1990, is that the failure to produce deliverable nuclear bombs was one of the most important determinants of the apparent apartheid surrender.

The disintegration of the Soviet Union that followed President Mikhail Gorbachev's *perestroika* initiatives in 1985 became bad news for the ANC-led liberation movement and a mix of bad and good news for the beleaguered National Party (NP) government. It robbed the liberation movement of the material support for the logical exploitation of the newly liberated Zimbabwe, Mozambique and Angola to intensify the guerrilla war against South Africa, with her increasing security vulnerability. Moreover, the increasing emigration of white males to evade compulsory conscription and the lack of access to state-of-the-art hardware and spare parts further undermined the military strength and the morale of the SADF. For the NP government, the end of the Cold War and the cover it provided for breaking international sanctions signalled

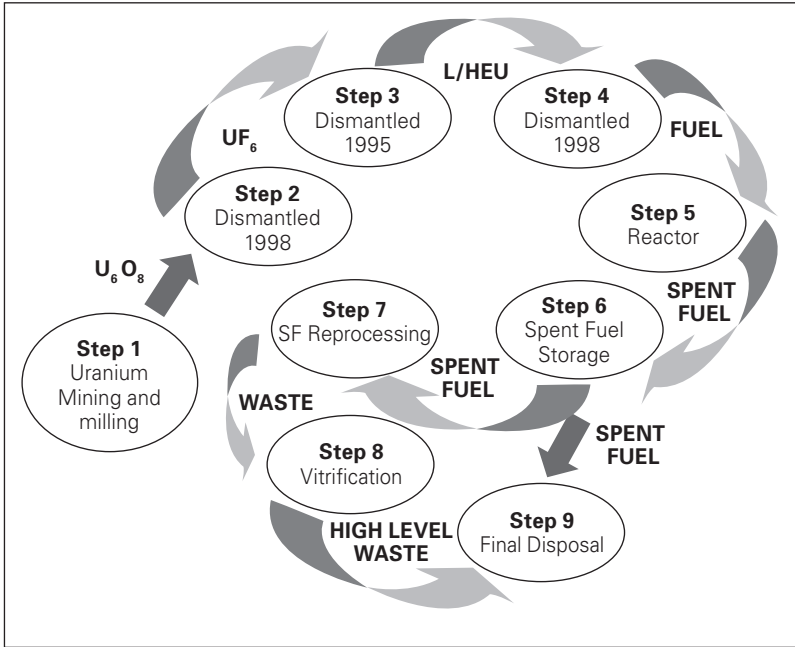
an increase in the global outcry against the moral repugnance of apartheid. The NP government also foresaw with fearful certainty the loss of any further Western support, particularly from the United Kingdom, the United States and France. Consequently, the liberal faction of the ruling NP led by FW de Klerk moved quickly to snatch power from the renegade President PW Botha and successfully enticed the ANC with the imminent transfer of power to the black majority.

In 1991 the De Klerk government acceded to the Nuclear Proliferation Treaty (NPT) on behalf of South Africa as a non-nuclear weapons state after about 20 years of evasion. Not only did South Africa gain moral credibility, but by acceding, South Africa did not have to account for the nuclear material that was in its possession before signing the treaty, making the concealment of any developments associated with the nuclear weapons programme even easier. While the negotiations for the transfer of power were proceeding at Kempton Park, the outgoing De Klerk administration appears to have hurriedly implemented a complete nuclear de-industrialisation policy by stealth, using the world-acclaimed nuclear weapons rollback as a cover. This policy was clearly spurred by concerns over the possible exposure of the full extent to which the Western powers collaborated with apartheid in the clandestine development of nuclear weapons. The speculated transfer⁴⁶ of nuclear weaponry technology to the allies of the liberation movement such as Libya and the Palestinian Liberation Organization (PLO) that were regarded as a threat to the interests of the West appears to have also been a major consideration in the pursuit of the total nuclear rollback.

The 1990 closure of the Y-Plant became one of the early collateral damages of the weaponry rollback that started the removal of the crucial uranium enrichment step of the nuclear fuel cycle. This step was completely removed later in 1995 with the dismantling of the Z-Plant that was commissioned in 1984 to provide LEU on a commercial basis. The closure of the Y- and Z-Plants eliminated Step 3 of the fuel cycle. Owing to the closure of the enrichment plants and the uranium glut in the nuclear markets, the operation of the Conversion Plant or Step 2 ceased in 1998.

As a knock-on effect of the initial end of Steps 2 and 3, Step 4 of the fuel cycle, the LEU fuel fabrication factory, codenamed the BEVA Plant, which was commissioned in 1986 to supply Koeberg power station, was removed in 1998. Within four years of the new democratic dispensation, the entire uranium beneficiation industrial complex was decommissioned, with manufacturing plants dismantled and sold as scrap

Figure 2.4 Post-1994 SA nuclear fuel cycle devoid of uranium beneficiation industrial complex



metal or wholly, for a tiny fraction of their development cost. The South African nuclear fuel cycle was then reduced to a typical set of facilities that are essential for an underdeveloped community to export its raw materials and import the finished essential products.

Post-Apartheid Nuclear Vision Deficiency Disorder

Owing to the lack of a new nuclear vision and guidance, the last apartheid government policy of comprehensive de-industrialisation continued unabated well beyond 1994. This erosion of the nuclear technology edge was made worse by the mass exodus of white nuclear professionals and the lack of their replacement. Ironically, the rapidly downsizing AEC had adopted a policy of deracialising its historical whites-only staff profile, employing its first two black scientists at the end of 1992. The apparent intention of this deracialisation policy was subsequently suggested by the words of one member of the AEC old guard, reported by a

disgruntled white scientist who preferred to remain anonymous for fear of reprisals: '[W]e will give blacks the senior positions and related big salaries and perks...they will purchase houses in the white suburbs and buy German luxury cars, they will not have to dirty their hands but we will carry on with our business as usual.' The commitment of the AEC to transformation was further questioned when the old guard overlooked suitably qualified, internal black candidates for appointment to the very first executive management position that became vacant, as the corporate policy required. Instead, one grossly underqualified and undocumented African immigrant was appointed, despite mandatory stringent top security clearance requirements of the corporation in 1996.⁴⁷

The post-1994 science and technology policies that promoted the commercialisation of scientific research and development activities in public institutions, and the merger of the majority of the universities that were mostly attended by black students have contributed greatly to the demise of South Africa's nuclear industry. The universities' merger, shortly after escaping the constraints that apartheid had placed on their scholarship, has paralysed these institutions.

In particular, this merger undermined the implementation of proactive initiatives such as the provision of the targeted graduate training programmes to contribute to the scientific skill diversification and redress of racial imbalances – for instance, the nuclear industrial collaborative graduate school in applied radiation science and technology offered under the auspices of the University of North West.⁴⁸ In this instance, the initiative was undermined by the political dynamics of the merger of the Potchefstroom University and University of North West, which had diametrically opposed organisational cultures. Notably, the former university's education was emphatically founded on puritanical values of Calvinist religious inclinations, while the latter's was secular. Moreover, the government policy of the ruling party cadre deployment to public service had led to often disastrous appointments of unqualified persons to strategically important positions of responsibility that required a mix of considerable industrial experience in nuclear science and technology and related management.

The Nuclear Energy Act 46 of 1999 that established the South African Nuclear Energy Corporation (Necsa) officially marked the demise of the nuclear fuel cycle and, by extension, the nuclear energy R&D capability it supported. What was then left of the industry were mainly the project management activities for the development of the Pebble Bed Modular Reactor (PBMR) project, commissioned in 1998 and implemented

through considerable outsourcing of requisite expertise; the operation of Koeberg nuclear power station; the management of radioactive nuclear waste primarily from the nuclear power station and radiation medical hospital departments; radionuclides' production; and largely accelerator-based scientific research at iThemba LABS.

That the Electricity Supply Commission (Eskom), a utility company that is not a properly equipped statutory nuclear research and development entity, realised its post-1994 aggressive bid to develop a new generation of reactors, may be attributed to the frenzy of commercialisation of public R&D. This was despite the existence of the AEC, which was a legally constituted nuclear R&D institution, better equipped for the very purpose of developing nuclear reactors. Moreover, an institutional review of the AEC commissioned by government in 1997 appears to have legitimised the pre-1994 AEC commercialisation component of the apartheid strategy to guide the wholesale nuclear de-industrialisation. The review particularly recommended the establishment of a splinter private commercial nuclear entity based on saleable AEC R&D output, and the continued public funding for decommissioning and decontamination, as well as the long-term management of radioactive nuclear waste.⁴⁹ Eskom was, however, endowed with appropriate political connections through its top leadership and a number of the ruling party loyalists on its payroll. This staffing arrangement appears to have facilitated much lobbying of the top government decision making in favour of the commitment of public resources for the pursuit of the defunct PBMR project.

According to the former Public Enterprises Minister Barbara Hogan, approximately \$1,3 billion⁵⁰ had been spent on the PBMR project in the 10 years before October 2010 when it was cancelled. Approximately \$4,7 billion in today's dollar value was spent between 1952 and 1978 to develop the nuclear fuel cycle.⁵¹ Therefore on average, apartheid South Africa developed and productively operated a nearly complete nuclear fuel cycle over 26 years at an annual rate of spend that amounted to 60 per cent of the defunct PBMR project alone during the democratic order. The minister's claim that the 'PBMR programme was instrumental in ensuring that South Africa retained a substantial nuclear skills base and associated industries' appears to be contradicted by the unabated departure of nuclear professionals from the industry and the loss of publicly owned intellectual property (IP).⁵²

More disturbing are the emerging revelations that some of the post-apartheid bureaucrats and politicians, who were instrumental in the

pursuit of ineffectual national nuclear and related policies at the outset, are also quitting the ailing public industry.⁵³ In leaving, they are not only taking along the corporate memory, but also IP, reportedly to set up private enterprises or leverage personal benefits abroad.⁵⁴

Sabotage of African Nuclear Power Potential

At the outset, Africans as subjects of Belgian and apartheid South African subjugation, were deliberately excluded from any meaningful developments of national nuclear enterprises. In addition, the African post-liberation initiatives to develop the requisite expertise and absorptive capacity to benefit from nuclear capability sustainably were snuffed out by a deliberate erosion of the developed technological base and existing related operations before hand over of control to the African majority. In this respect, the colonial Belgians were particularly blatant, when they flooded the fully operational Shinkolobwe uranium mine and sealed its shaft with concrete, before the handover of political power to Lumumba's visionary and radical African government. Apartheid South Africa was rather more subtle in its rapid dismantling of the nuclear industrial complex before the 1994 democratic elections, clearly exploiting the lack of a nuclear strategic outlook of the then anti-nuke and unsuspecting incoming government of the ANC.

The common effect of the outgoing repressive regimes of Belgian Congo and apartheid South Africa has been that of exacerbating the constraints of the lack of a mature scientific and technological culture, let alone a critical mass of requisite skills, to which the potential for the free-and-independent Africans to derive the benefit of nuclear power was subjected. The Belgian colonialists ensured the resumption of their dominance of Congolese economy including any nuclear agenda by establishing a neocolonial government after the removal of Lumumba from power and his brutal assassination with the aid of the US CIA. In respect of South Africa, it would appear that the control of the post-1994 nuclear agenda and the fate of the industry by the apartheid technocrats resulted from the determined emasculation of the ruling power by outgoing President de Klerk's negotiators before hand-over to the ANC. Moreover, the science and technology policies that legitimised the calculated demise of the South African nuclear fuel cycle were formulated in consultation with an industrial lobby group, the National Science and Technology Forum (NSTF), which primarily represented the interests of untransformed public and private entities.⁵⁵ This tendency is

consistent with the established pattern of dominance in other strategic areas of the economy, including finance, banking, agriculture, and trade and industry in which the apartheid old guard retained crucial leadership positions well into the new post-apartheid era.

In the particular case of South Africa, the latent demise of her nuclear industry in the event of African majority domination was nurtured by a toxic mixture of a myriad policies of racial exclusion, secrecy, blackmail and deceit that guided R&D and bound its civilian and military end-users together during the apartheid era.⁵⁶ Firstly, the end of the Cold War denied South Africa the hitherto convenient cover to receive further nuclear technology from sympathetic Western nuclear powers.

Secondly, the exclusion of the African majority from the national science and technology affairs narrowed the national pool of talent for any maintenance of the nuclear technology edge and severely limited its growth and exploitation in post-apartheid human development.

Thirdly, the emigration of white South African citizens, mostly with exclusively acquired professional skills further emasculated the narrow skill base.⁵⁷ This skill base has continued to be eroded by the unabated dearth of new blood and natural attrition in the past two decades.

Fourthly and, most significantly, the post-apartheid governments have failed to provide an alternative nuclear vision to guide further developments in a manner that is commensurate with the minimum standards of a democratic society. The de-industrialisation and commercialisation policy that was initiated before 1994 to stealthily induce the end of the public nuclear industry was pursued under a convenient cover of nuclear weapons rollback. This industrial sabotage has since been legitimised by the equally opaque post-apartheid science and technology policies that promote the commercialisation of the public R&D enterprise. As with most profit-seeking motives, these policies are inherently detrimental to any mass development, particularly in respect of redress of the racial inequities of apartheid.⁵⁸

South Africa and the DRC, respectively, exemplify typical states of unconsolidated and non-existent democracy, which are the persistent hallmarks of neocolonialism in twenty-first century Africa. In this respect, the ruling elite abuse political power in their exploitation of the national economies for their short-sighted material gain and benefit of their cronies. Moreover, in their quest for hard currency primarily for the import of foreign technology, services and their consumer goods, the tiny African ruling elite, who display similar tendencies of consumerism as the bulk of the middle and upper classes of the Western

developed communities, comply with the often grossly inappropriate funding requirements of the international finance institutions (IFIs) for the implementation of national development plans. These funding requirements primarily cater for the vested interests of the enterprising global elite and world powers who are the main beneficiaries of the transnational companies that invariably lead the implementation of the major commercial activities of the finance national projects. In this scheme of things, the development aspirations of the vast majority of the Africans are shelved, only to be revisited rhetorically during the campaigns for votes.

The IFIs such as the World Bank and International Monetary Fund (IMF) and their sponsoring world powers are characterised by their strong commitment to the notion that private property rights as well as free trade and markets are essential for attaining the national goals of human development through enterprise that is free from the regulatory interventions of the state. This notion is used to justify the often aggressive pursuit of human development through the creation of markets and privatisation by any means necessary. For example, whole communities may be moved from their traditional land of residence and life sustenance by force to pave the way for the development of mining operations by private entrepreneurs who have connections with the unscrupulous ruling elite.

The soaring corruption coupled with crippling ineptitude in African public service is one major threat to African social and economic advancement in general, and the development of nuclear capability in particular. The mismanagement of the gross nuclear safety and security breaches in the DRC in 2006⁵⁹ and South Africa in 2007⁶⁰ are just two examples of unabated corruption and incompetence at very high levels of African public service. The appalling lack of security around the DRC TRIGA facilities; the disappearance of weapons grade reactor nuclear fuel elements; and the apparent exoneration of all the public servants from the gross negligence of duty could not have taken place without express collusion of highly placed decision makers, possibly for personal material gain.⁶¹

The tardiness and 'not-a-big-deal', laid-back manner with which the near-miss raid on the high security South African Necsa facility was handled by its nuclear authorities suggests the incident was a sanctioned inside job. The authorities have attempted to dismiss the mysteriously well executed security breach as an act of random criminality and discounted the possibility of the involvement of sophisticated terrorists.

Their explanation rings hollow, considering that the raiders penetrated the emergency control centre of the facility without being detected, despite the presence of a 10 000 V perimeter fence that is an integral part of a very sophisticated electronic surveillance network. That no one in the response line management of the Necsa site was held accountable for the glaring negligence of duty following this raid, again suggests a questionable collusion by higher authorities in the seeming inside job that went horribly wrong. The reasons behind this incident and its sub-standard handling by the authorities will remain a subject of speculation until a proper investigation is launched and decisively concluded.

The globally reported DRC and South African nuclear safety security breaches, including the unconvincing responses of the respective nuclear authorities, have strongly reinforced the global Afro-phobic characterisation of Africans as inherently corrupt, incompetent and therefore not worthy custodians of nuclear power technology and materials. It is therefore not entirely coincidental that soon after the Necsa raid news emerged about the US-sponsored switch-over use of weapons grade HEU to LEU in the production of molybdenum-99 (Mo-99) for generation of technetium-99.⁶² This is despite the inefficiency of the Mo-99 production process when LEU is used. Moreover, the blended fuel produces much larger amounts of nuclear radioactive waste and therefore more spend for its management on the account of the unsuspecting taxpayers. Clearly the US motive in such sponsorships is to ensure that the weapons grade HEU that is currently possessed by the mistrusted nuclear nations is eventually down blended for her considered security reasons. Considering the cost entailed in the provision of weapons grade HEU, including all the associated scientific research, technology development and the elaborate capital outlay of the requisite infrastructure, its maintenance and radioactive waste management, a switch-over to the use of LEU would not be an option, because it does not make any economic sense.

The unfolding fallout of the March 2011 nuclear accident at the Daiichi nuclear power plants in Fukushima, Japan – the worst since the Chernobyl disaster – poses a major threat to any opportunity for Africa to harness nuclear power in human development as much as it suggests a global recession in the nuclear power industry. The strong earthquake that struck off the north east coast of Japan and triggered a major tsunami, caused power failure that disabled the cooling system for the reactors and spent fuel stored on site. The loss of cooling and explosions following hydrogen build-up in the plant housing respectively led to

the multiple reactor meltdowns and the escape of radioactive material, contaminating the surrounding environment and beyond the Japanese borders. The Fukushima accident and its handling by the Japanese plant operator, Tokyo Electric Power Company (TEPCO) and regulatory authorities, respectively exposed the vulnerability of nuclear energy provision to major and inevitable disasters such as quake-tsunamis as well as the New York 9/11-type terror attacks, and the weakness of current nuclear safety practices under this set of circumstances.

Moreover, the Fukushima disaster has ratcheted up the fierce debate on the wisdom of the current and future expansion of nuclear energy generation globally. This has led some countries, such as Germany and Italy, to completely eliminate the nuclear option from their energy policies.⁶³ Other countries such as China have decided to reduce the target expansion of their nuclear energy provision, while others such as the US are considering a moratorium on newly built projects while undertaking extensive review of nuclear safety practices and related regulations.⁶⁴ Such a review is likely to address the impact of global warming on the safety of the nuclear power generation because of the scientifically observed relationship between glacial melting and increased seismic activity, tsunamis and floods, among other changes in climatic patterns.⁶⁵ As expected, the global trend in energy provision since the Fukushima disaster is characterised by the reinvigoration of the civil campaign for renewable energy provision and increasing prominence of related scientific research, development and demonstration (RD&D) among the developed communities.

The looming global recession across the nuclear industry as well as the financial meltdown due to the persistence of preferential trade in speculative financial markets by the owners and controllers of capital, as opposed to investment in productive economic activity, is constraining Africa's ambition to develop any scientific and technological capacity to harness nuclear power significantly. Despite the shortcomings of the nuclear energy technology as well as safety and regulatory practices exposed by the Fukushima disaster, nuclear energy technology continues to hold a great potential for the reduction of GHG emission through other climate friendly applications other than electricity generation. The production of hydrogen which is widely used in agriculture, food industry, petrochemical industry and clean transportation among other applications, causes huge amounts of GHG emission, notably carbon dioxide due to the intensive use of fossil fuel to produce process heat for the high temperatures required in water electrolysis. The required high temperatures may not be produced by renewable energy systems as yet. When a nuclear reactor

is used to provide process heat, the GHG emissions are completely eliminated. Research is underway in leading nuclear industrial countries to harness high temperature gas cooled nuclear reactors to provide process heat in order to yield even higher temperatures, in order to improve the efficiency of electrolysis for hydrogen production. Thus nuclear energy will continue to play an important role in the 21st century green economy, in which Africa's competitiveness would not be enough if her nuclear technological potential would not be exploited.

Conclusion

The motives for both the development and destruction of DRC uranium mining and the South African nuclear industry are clear. However, the apparent collusion of the post-liberation African ruling elite in the neocolonial denial of Africa to develop scientific and industrial capability to beneficiate uranium for economic development is inconceivable. This is particularly disconcerting because the African people have been made to pay repeatedly for their own subjugation in this respect. In the case of South Africa, Africans have firstly had to pay for the odious debt of the defunct apartheid nuclear fuel cycle and weaponry programme. Secondly, they have recently been made to pay for the failure of the controversial PBMR project, the commissioning of which resulted from industrial lobbying that sidelined the legally constituted public entity, the former AEC. Thirdly, they and their future generations will continue to carry the collateral burden of having to manage the radioactive nuclear waste arising from the activities that were primarily intended to sustain the regime that subjugated and dehumanised them. The key feature of this collusion appears to be the utter disdain with which the majority electorate appears to be persistently treated by the ruling elite, which is evident in their gross mismanagement of the electoral mandate.

Despite all the teething problems of her democracy that threaten to drag her backwards, South Africa is presently Africa's scientific and technological powerhouse, with considerable potential to rebuild her industrial capacity for the beneficiation of uranium. However, South Africa's realisation of this potential is severely constrained by the failure of her leaders to heed valuable post-liberation African lessons, particularly from her neocolonial experiences. For example, by legitimising the systematic nuclear de-industrialisation through the post-1994 implementation of ineffectual commercialisation and rushed privatisation of

the inherited spun-off scientific R&D output, South Africa demonstrated her failure to learn from the Congolese experience. After the indigenous Congolese had been deprived of the scientific and technological expertise to benefit from their uranium by the departing Belgians, they had to watch as their corrupt new leaders blatantly stifled any continuity of the mining operations for their own economic advantage. Similarly, the opaque neo-apartheid management of the public nuclear enterprise, including the defunct PBMR and the IP flight, has catapulted post-1994 South Africa into a development trajectory of being merely exporters of raw uranium resources and retarded her nuclear scientific and technological advancement greatly.

The South African government plans to spend a minimum of approximately \$125 billion⁶⁶ on energy infrastructure, including the extension of the nuclear capacity for provision of electricity in the near future. It may be advisable for South Africa to take a leaf from the book of the US and place a moratorium on the implementation of the plans to erect new nuclear power plants in order to derive any benefit of the emerging lessons from the Fukushima accident. Furthermore, the disturbing lessons learnt from the fruitless PBMR enterprise necessitate the prevention of the repeat of wasteful expenditure in a country which can ill afford it. In this respect, a full public inquiry into the historical and current developments of the nuclear industry needs to be considered urgently. This inquiry may be necessary lest an unsustainable precedent is set for the opaque pursuit of ineffectual energy, science and technology policies, which have exposed the national technology edge to a risk of irreversible damage. The involvement of a business lobby entity, NSTF, in the development of these policies has repeatedly undermined the electoral mandate, in that the general populace did not enjoy the extensive consultation that was reserved for lobbyists.

Africa has sustained colonial, apartheid, neocolonial and neo-apartheid pillage of her vast uranium resources to support foreign strategic and commercial interests. African people, whose labour has been exploited extensively in the process, have also been denied the full benefit of nuclear technology, through a calculated sabotage of their intellectual development in the past, as well as corruption and ineptitude in public service after their liberation from colonial and apartheid subjugation. Despite these set-backs, Africa continues to be resilient and has all the requisite resources for the exploitation of nuclear power to fuel her human development requirements in the twenty-first century. By virtue of her regional economic and technological dominance, it is South Africa's

moral duty to put her own house in order and to provide leadership in the quest for the realisation of the African nuclear power potential.

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State of energy infrastructure in Africa

How much investment is needed to migrate to renewable energy?

Walid El-Khattam, Salma Hussein and Mohamed Abdel-Rahman

Introduction

Africa is the second largest continent with an area of 30 million km², representing 15 per cent of the Earth's area, 2 per cent of its industrial capacity, 15 per cent of its average per capita income, and 3 per cent of its energy consumption.¹ As of 2006, less than 15 per cent of Africa's population had access to electricity, which, in addition to being scarce, is also unreliable. The obvious factor shaping this scarcity is that many sub-Saharan and sub-equatorial African countries are generally economically poor and specifically have limited electricity infrastructures.²

Focusing on the electricity power sector, we find that the economics of energy development and the processes of integration in Africa are obstructed by a lack of sound infrastructure. Poor energy infrastructure has created the largest deficit in the power sector. As a result, a large number of African countries are facing regular blackouts due to power shortages. Only 25 per cent of Africans have access to electricity,³ even after the installation of backup generators, which cost three to four times as much as the cost of utility grid electricity. Moreover, the worst cases of electricity access occur in rural areas, where only a small number of households have access to electricity due to a lack of affordability or availability of electric power. This is considered to be a critical situation that needs Africa to further build, invest in and encourage investments in energy infrastructure.

Statistics show that a significant amount of Africa's generating capacity is not in a usable and/or suitable state. These conditions are considered to be the consequences of a lack of long-term planning, insufficient investment, poor maintenance and the inefficiency of existing power utilities. While, on the other hand, in the short term, other factors also play a role in shaping this inefficiency, such as high economic growth, conflict and constantly rising oil prices.

To increase electricity access, new generation capacity and transmission grid enforcement need to be added, and customers need to be connected to the grid. This would require tremendous investments to cover capital expenditure and operations. In attempting to minimise the individual nations' investment costs and obtain the full benefit of available energy resources and reserves, African countries have been integrated into regional power pools. Although these power pools assist in facilitating access to electricity transmission, they require further infrastructure planning and investment.

Because Africa is rich in renewable energy resources, renewable energy is considered a key means of covering the lack of power without dependence on fossil-fuel price fluctuations. With the existence of workable integrated power pool infrastructure, remote and local renewable energy resources can be integrated into the existing African electricity grids. However, in order to establish how much investment is needed to migrate to renewable energy in Africa, the question which arises is how to mitigate the existing infrastructure problems in the African power sectors, that is, in each individual nation and each power pool.

This chapter seeks to create an understanding of Africa's energy resources (traditional and renewable), reserves and infrastructure. Data collection and analysis on the status of the main grid infrastructures, including energy information, are presented. A thorough evaluation of the existing infrastructure assets is given and policy reforms are investigated. This evaluation is used to assist policy makers in setting priorities for current/future infrastructure investments and to provide a baseline for monitoring progress. Investigations of the use of renewable facilities and their necessary investments to overcome the power deficit are reported and discussed.

Overview of Africa's Sub-Regions and Power Pools

The African continent and its islands can be divided into six sub-regions, according to the common features in terms of geography, resources,

economics, cultures, traditions and customs, see Map 2 on page 94. The 54 African states make up the sub-regions as follows:⁴

F	North Africa	(6 countries) Algeria, Egypt, Libya, Western Sahara, Morocco and Tunisia.
D	West Africa	(16 countries) Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo and Cape Verde.
C	Central Africa	(8 countries) Cameroon, Central African Republic (CAR), Chad, Congo, the Democratic Republic of the Congo (DRC), Equatorial Guinea, Gabon and São Tomé and Príncipe.
B	North-East Africa	(10 countries) Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, South Sudan and Tanzania.
A	Southern Africa	(9 countries) Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia and Zimbabwe.
E	Western Indian Ocean	(5 countries) Comoros, Madagascar, Mauritius, Reunion and Seychelles.

This division will better clarify possible energy investment solutions through regional energy integration, since the geography of energy supply options does not necessarily correspond to political boundaries. For example, the cleanest and cheapest energy source may lie across national borders; while traditional national energy markets are often too small to justify the investments needed in particular energy supply options. At the same time, political instability and the lack of infrastructure make distribution of supplies difficult. Therefore, in the past decade, a number of power pools have been set up in Africa's sub-regions to overcome the above mentioned energy distribution problems. In August 1995, the Southern African Power Pool (SAPP) was created through a Southern African Development Community (SADC) treaty and aimed to optimise the use of available energy resources in the SADC region. Since then, other power pools have been created, such as the West African Power Pool (WAPP), Central African Power Pool (CAPP), and the East African Power Pool (EAPP).⁵

Africa's Current Energy Resources

A 2004 survey of energy resources conducted by the World Energy Council (WEC) reported that Africa has more than enough resources to satisfy all its energy requirements. In terms of fossil fuels, 7,1 per cent of the world's known oil reserves and 7,5 per cent of the natural gas reserves are found mainly in North and West Africa.⁶ Africa possesses 10,6 per cent of the world's coal reserves, of which almost 96 per cent is produced in South Africa. In the case of hydropower, approximately 13 per cent of the world's hydropower is generated by the Congo, Nile, Niger, Volta and Zambezi rivers. Many other energy resources are available in Africa.⁷

Africa's current energy resource status can be evaluated through studying the distribution of the energy resources and available energy reserves in its sub-regions. This understanding will clarify the need for energy development on the African continent.

Africa's energy resources and reserves

Knowing the available African energy resources, makes it easier to understand what is needed and how Africa can benefit from all of its resources. Since, at present, Africa suffers an extreme deficit in its reserve capacities, the optimal use of its resources will occur when Africa faces all its challenges and needs, which will finally lead to adequate infrastructure and energy reserves in its energy sector. The status of each energy resource is investigated and evaluated below in order to map Africa's resources and reserves.

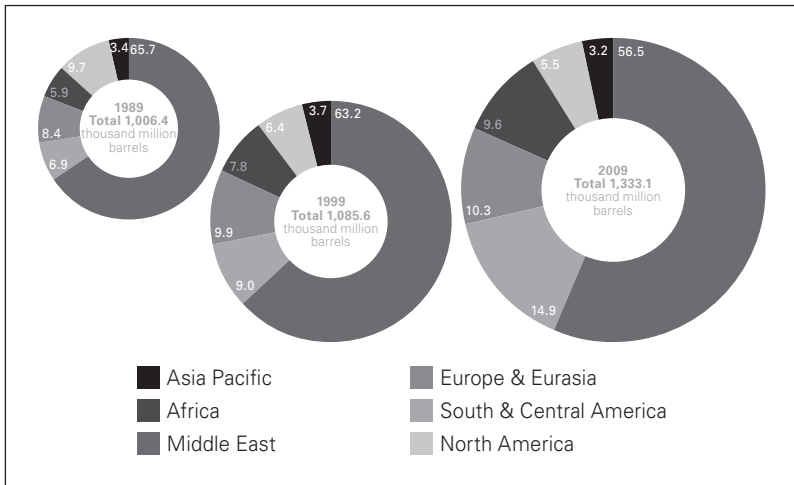
Non-Renewable Energy Resources

Oil

Oil reserves

The oil industry is a key development field on the continent of Africa. Statistics show that approximately 89 per cent of oil reserves in Africa are in the north and west: Algeria, Libya, Egypt, Sudan, Angola, the DRC, Equatorial Guinea and Gabon.

According to the 2008 British Petroleum (BP) Statistical Energy Survey, Africa had proven oil reserves of 117,481 billion barrels at the end of 2007 (i.e. 9,49% of the world's reserves). Figure 3.1 shows the

Figure 3.1 Distribution percentage of oil reserve in 1989, 1999 and 2009

world's distribution percentage of oil reserves throughout 1989, 1999 and 2009.⁸

Oil production and consumption

At the end of 2007, Africa produced an average of 10,3176 billion barrels of crude oil/day (12,5% of the world total production with an increase of 3,1% compared to 2006).⁹

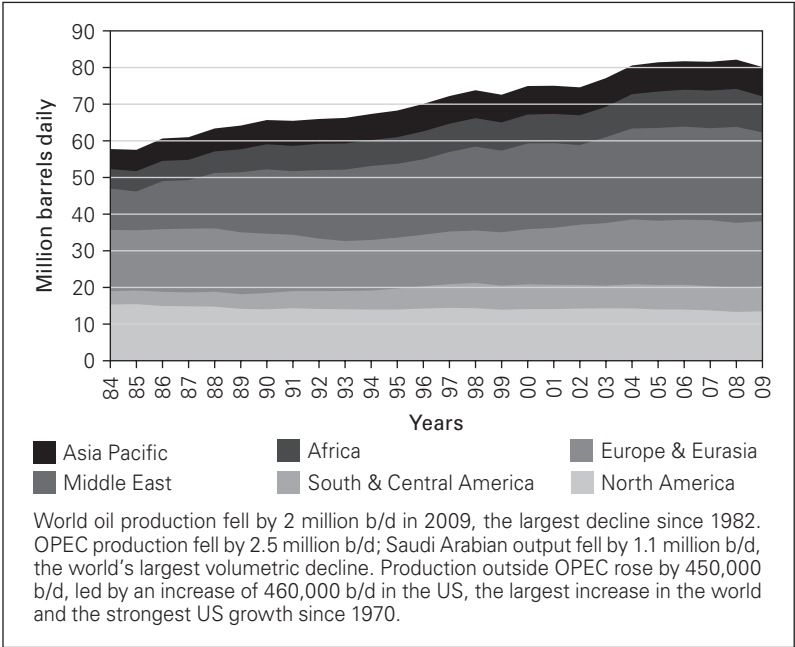
Figure 3.2 shows the world's production by region measured in million b/day for oil including crude oil, shale oil, oil sands and natural gas liquids (NGLs), and excluding liquid fuels from other sources such as biomass and coal derivatives. In 2009 Africa produced 9,705 million b/day (10% of the world production), with a reduction of 5,2 per cent with respect to 2008 values.¹⁰

Five countries dominate Africa's oil production. Together they account for 85 per cent of the continent's oil production. These countries, in decreasing production order, are Nigeria, Libya, Algeria, Egypt and Angola. Other oil producing countries are Gabon, Congo, Cameroon, Tunisia, Equatorial Guinea, the DRC, and Côte d'Ivoire.

At present exploration is taking place in a number of other countries that aim to increase their output or become first-time producers. Included in this list are Chad, Sudan, Namibia, South Africa and Madagascar.

In 2004 the oil industry comprised 44 refineries in 25 countries with a total distillation capacity of 3 million b/day which represents 4 per cent

Figure 3.2 The world’s oil production by regions (million b/day)¹¹



of the world’s total production. The major refining centres are in Egypt (19,2%), Algeria (16,7%), South Africa (15,6%), Nigeria (14,6%), Libya (11,6%), Morocco, (5,2%) and Kenya (3%). North and West Africa have

Figure 3.3 Africa’s oil production

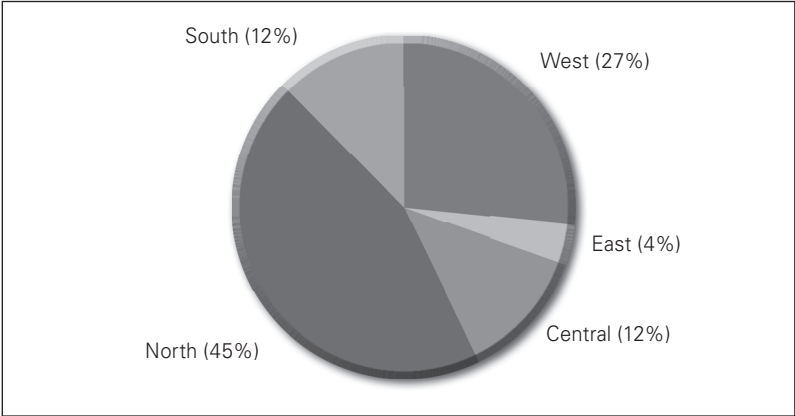
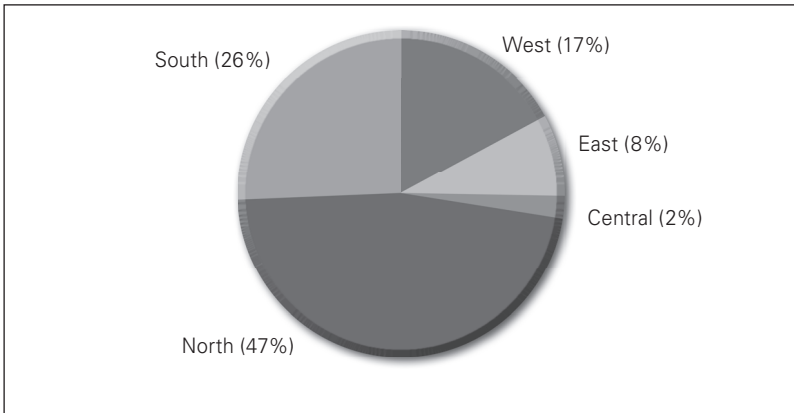
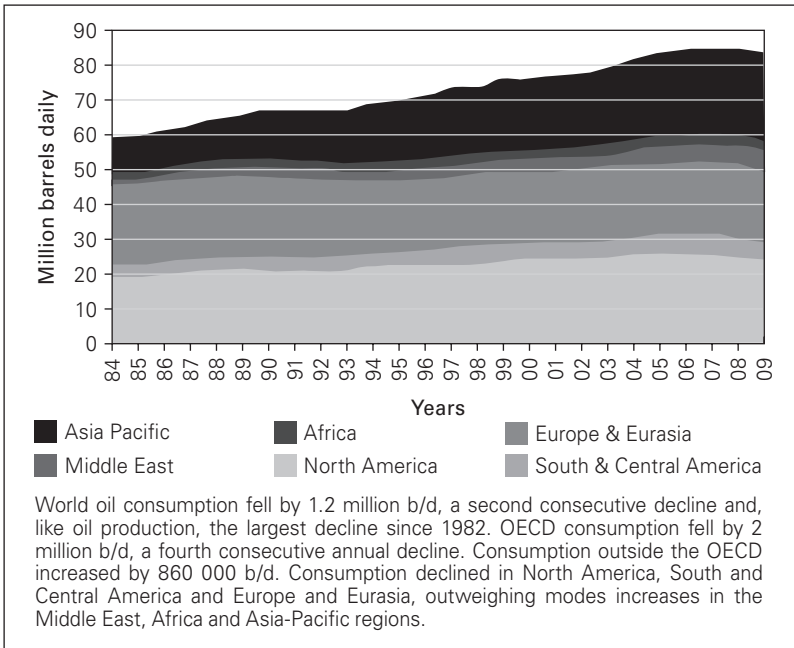


Figure 3.4 Africa's oil consumption

the higher share of the oil production and oil reserves. Approximately 70 per cent of African oil production is in Nigeria, Algeria, Angola, Sudan, Equatorial Guinea, Congo, Chad and Libya (see Figure 3.3).

Figure 3.5 The world's oil consumption by region (million b/day)

In 2004, the North led the African consumption with 47 per cent, leaving the remaining 53 per cent for Sub-Saharan Africa (see Figure 3.4).¹² In 2007, Africa contributed 12,5 per cent to global oil production but only consumed 3,5 per cent of the oil produced globally, making the continent a net exporter of oil.¹³ In 2009, Africa consumed 3,082 million b/day (3,7% of the world production), with an increase of 1,1 per cent with respect to 2008 values. Figure 3.5 shows oil consumption around the world in 2009 by region.¹⁴

Natural gas (NG)

NG reserves

Various 2004 studies reported that at that time more than 98 per cent of NG reserves were in North and West Africa, with 58 per cent of these reserves in North Africa (see Figure 3.6).¹⁵ By the end of 2007, Africa had more than 14,6 trillion m³ of proven gas reserves.¹⁶ Figure 3.7 shows the world's distribution percentage of NG reserves through 1989, 1999 and 2009.¹⁷

NG production and consumption

In 2004 more than 80 per cent of Africa's NG production was in the North (see Figure 3.8). Figure 3.9 shows the world production by region for NG, excluding gas flared or recycled.¹⁸ In 2009 Africa produced 203,8 billion m³ (6,8% of the world production), with a reduction of 4,6 per cent with respect to 2008 values (see Figure 3.8).¹⁹

Figure 3.6 Africa's natural gas reserves

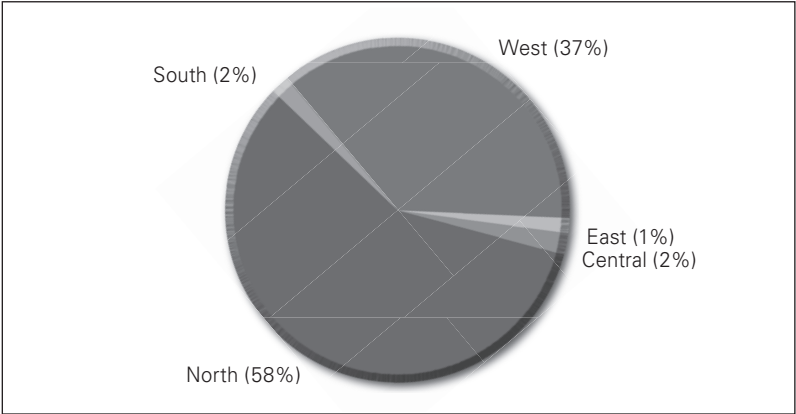
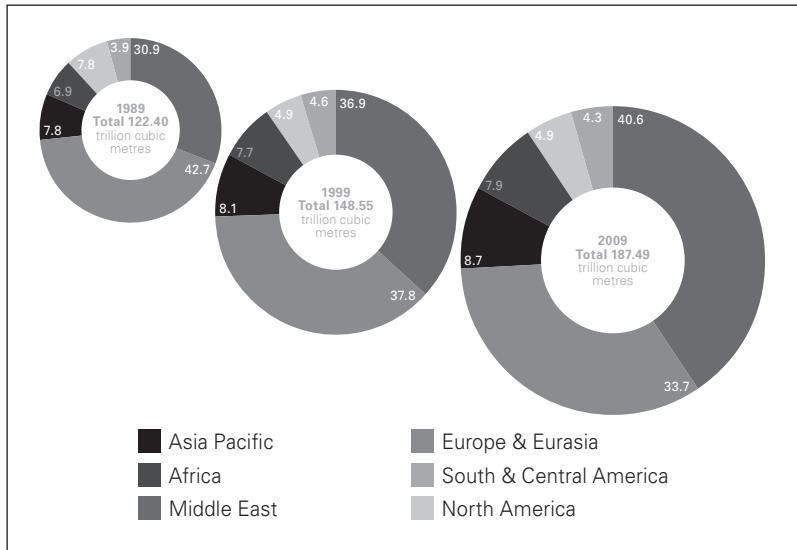


Figure 3.7 Distribution percentage of NG reserves in 1989, 1999 and 2009

North Africa was responsible for 82 per cent of NG consumption and left the rest of Africa with 20 per cent in 2004, (see Figure 3.9). However, in 2009, Africa consumed 94 billion m³ (3,2% of the world production) with a decrease of 1,9 per cent with respect to 2008 values. Figure 3.10 and Figure 3.11 respectively show the NG production and consumption worldwide by regions in 2009.²⁰

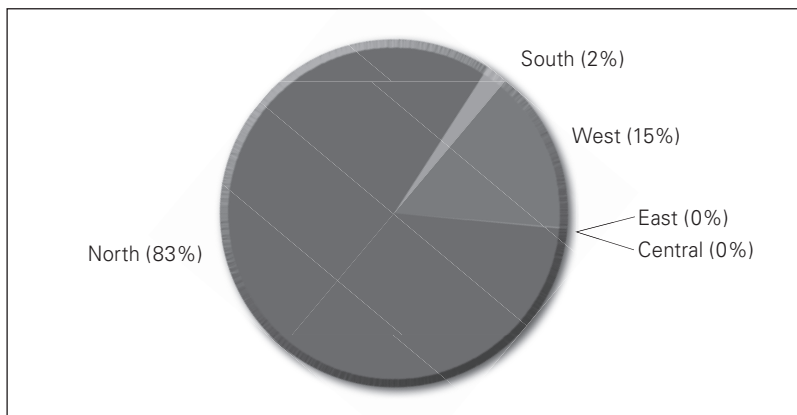
Figure 3.8 Africa's natural gas production

Figure 3.9 Africa’s natural gas consumption

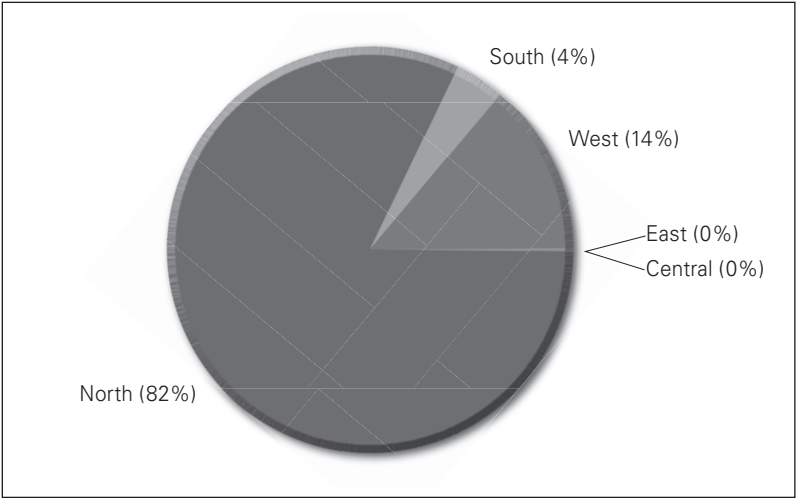


Figure 3.10 The world’s NG production by region (billion m3)

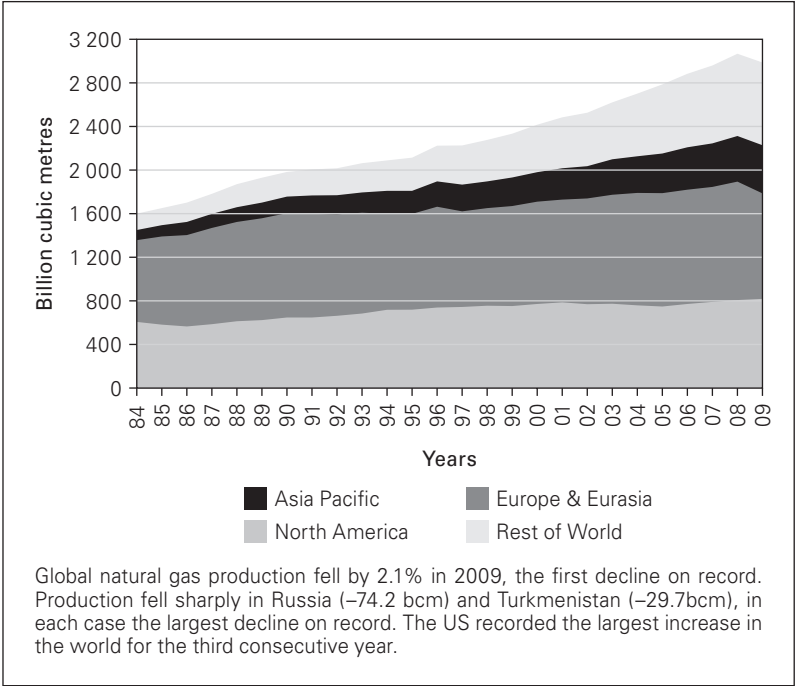
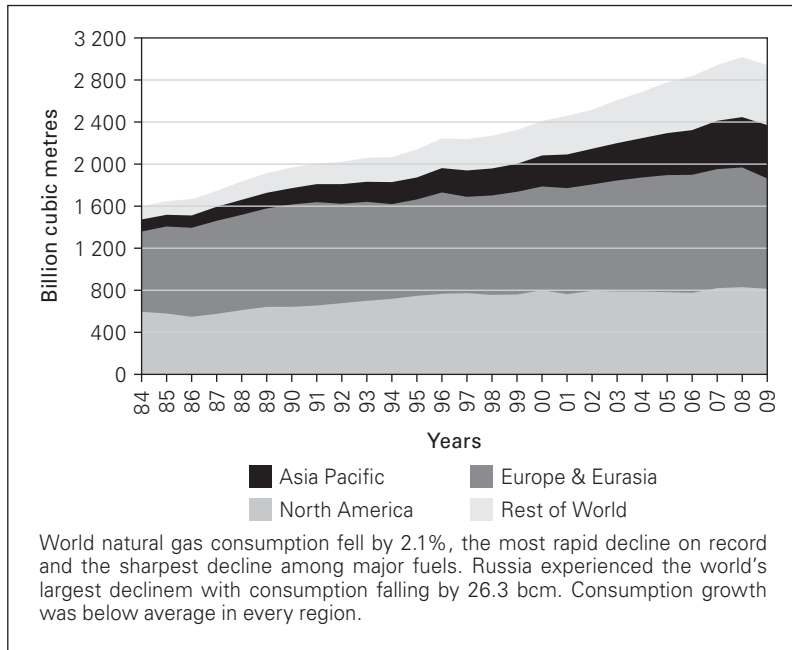


Figure 3.11 The world's NG consumption by region (billion m3)

Coal

Coal reserves, production, and consumption

Figures 3.12 and 3.13 show Africa's (in 2004) and the world's (in 2009) distribution of coal reserves respectively.^{21,22}

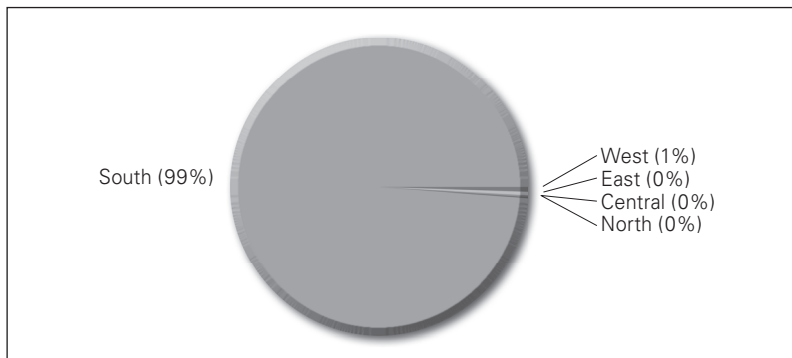
Figure 3.12 Africa's coal reserves

Figure 3.13 Proved reserves at end 2009

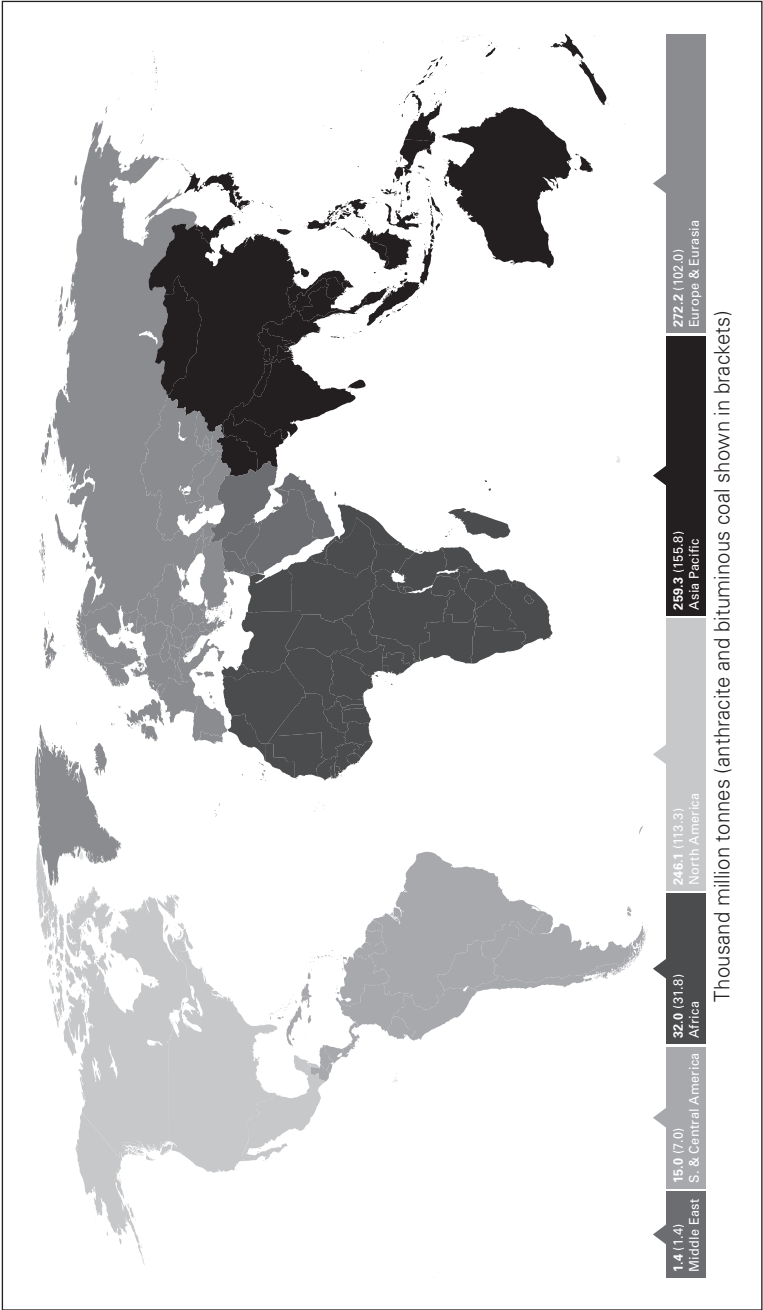
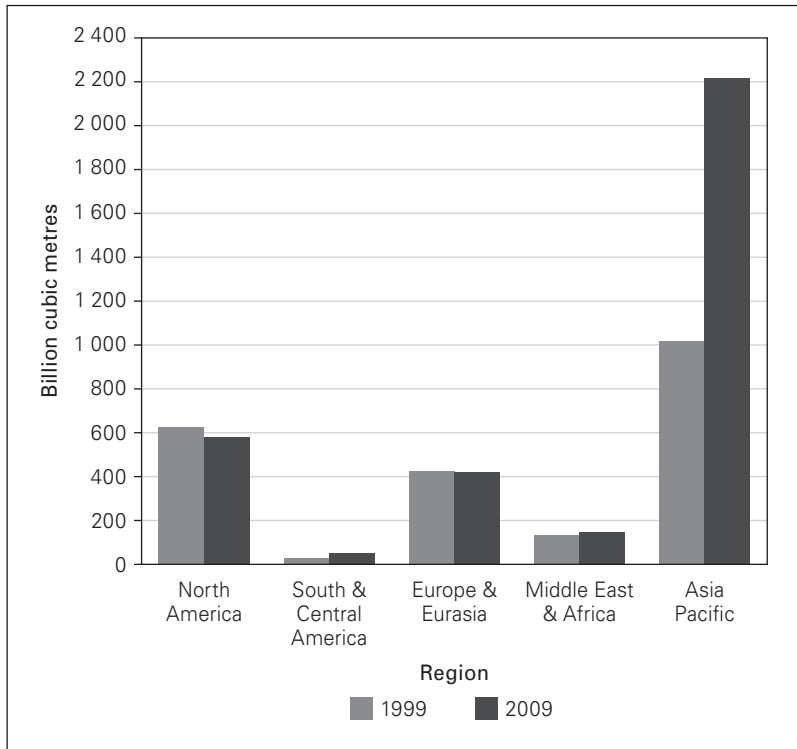
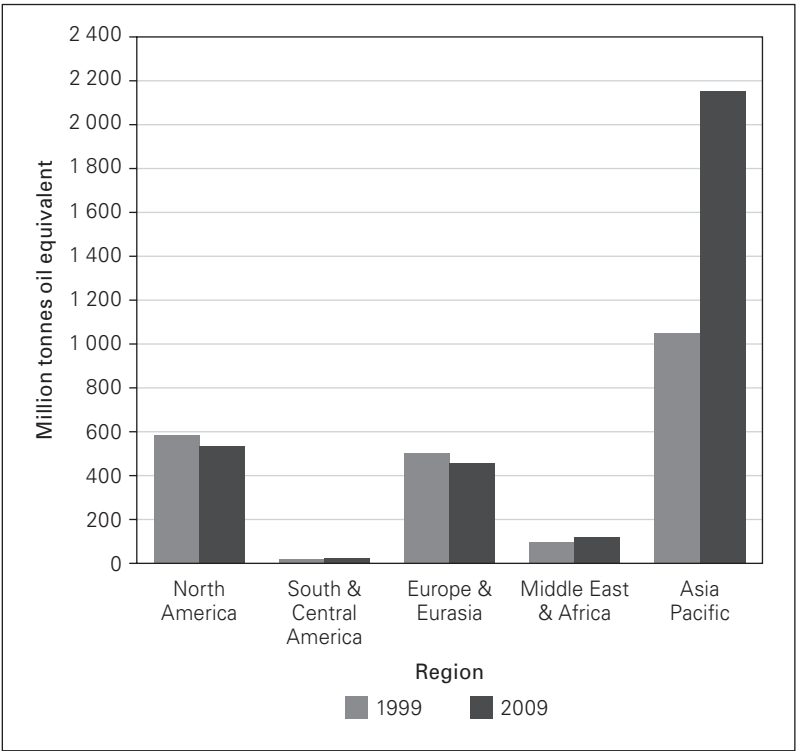


Figure 3.14 Production

Figures 3.14 and 3.15 show a comparison between 1999 and 2009 for coal production and consumption individually measured in million tonnes of oil equivalent (Mtoe). In 2009 Africa produced 143 Mtoe (4,2% of global production), with a reduction of 0,7 per cent with respect to 2008 values. However, Africa consumed 107,3 Mtoe (3,3% of global production), with a reduction of 3,1 per cent with respect to 2008 values.²³

Africa's coal consumption is expected to increase by 1,9 quadrillion from 2007 to 2035. South Africa currently accounts for 91 per cent of the coal consumed on the continent. Recent power shortages and a general lack of spare generating capacity in Southern Africa have led to increased interest in new coal-fired power projects. South Africa leads the continent in coal reserves, production and consumption and also exports some of its coal production to neighbouring African countries.

Figure 3.15 Consumption

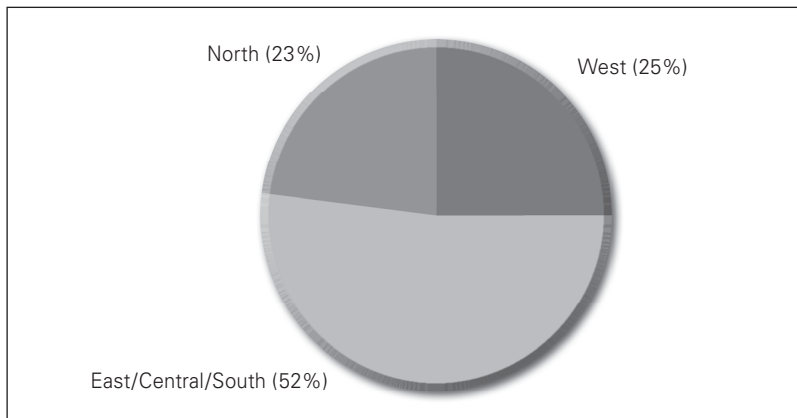


Renewable energy resources

Africa has promising renewable energy resources, such as hydro, wind, solar, geothermal, and biomass. Renewable energy technologies are often considered the most appropriate technology choice for much of rural Africa. They could provide a reliable alternative for many countries, including current oil-exporting nations, as many of them generate electricity from biomass, hydro, photovoltaic (PV) – in rural areas – and wind resources.

Hydroelectric energy

Fast-running water spins hydro-turbines to produce electricity. High rainfall areas and steep mountains are ideal for this type of electricity generation. At present, many large-scale hydroelectric generation

Figure 3.16 Africa's hydro generation

projects have been developed on the African continent. These large-scale projects require the building of large dams on rivers, which can be very capital-intensive and may cause severe negative impacts on the environment.

On the other hand, new small hydro generation or run-of-the-river hydroelectric schemes can be a viable alternative to large hydro investment as they cause less environmental damage and require fewer investments. The run-of-the-river schemes divert only part of the river through the plant turbines by harnessing the natural gravity of the river flow to produce electricity. As there are a lot of rivers flowing in Africa, the new type of generation should be one of the most favourable technologies for Africa's future.²⁴

At present, there is a tremendous hydropower potential in Africa. It is estimated that the continent has 1,750 TWh potential in hydropower, whereas only 5 per cent of the continent's potential of hydropower has been exploited.²⁵ Hydropower distribution among African countries is shown in Figure 3.16 and it is considered to be a very low percentage compared to the current global hydropower production.²⁶

Biomass energy

Biomass comprises plant and animal waste that is used as a source of energy to generate electricity. An increasing number of biomass renewable energy projects have been developed in Africa, resulting in positive impacts on the environment.

Unfortunately, at present, direct wood burning is a major energy source for food preparation for the average citizen. This has huge negative impacts on the environment.²⁷ Thus, considering traditional biomass-burning wood, more than 80 per cent of the total African population relies primarily on biomass for its energy needs. In some countries, biomass accounts for 70 to 90 per cent of primary energy supply, and as much as 86 per cent of energy consumption.

Africa's biomass resources are estimated at 82 billion tonnes. As the absolute number of people in Africa increases from 583 million in 2000 to 823 million in 2030 (an increase of approximately 27%), so the use of biomass will increase.²⁸

Solar energy

Solar energy is produced from sunlight and heat energy. Sunlight is converted by solar cells into electrical energy using two main methods; solar or PV cells and solar thermal technology. Although using solar technologies to generate electricity is more expensive than using coal-fired power stations; it produces much less pollution.²⁹

The average solar intensity in Africa is between 5 and 6 kWh/m². Some encouraging results with PV systems have been achieved in Ghana, Kenya, Namibia, South Africa and Zimbabwe. An important driving force behind the wide use of PV technology in Africa is mainly in applications in rural areas. At present, several initiatives are under way in North and East Africa.

In addition to this, several countries in North Africa are planning to develop solar thermal plants of varying capacities with the financial and technological backing of European countries.

Wind energy

Wind energy has become one of the most mature renewable energy alternatives to the conventional fossil-fuel-based electricity generation. The development of wind electricity generation is largely driven by the public concern about global warming, limited fossil-fuel resources, and the provision of federal production tax credits. Records show that wind power generation has grown at an annual rate of 25 per cent since 1990 and has a great potential to be used in many regions of the world. The coastal areas in Africa have good potential to use wind generators.³⁰

Geothermal energy

Geothermal power use has numerous benefits over other energy sources, including near-zero emissions and small space requirements (11% of the total land used by coal-fired plants and 12 to 30% of land occupied by other renewable technologies).³¹ It is estimated that Africa has the potential to generate 14 GW; however, only 0,6 per cent of the continent's potential of geothermal has been exploited.³²

Overview of Africa's Electricity Accessibility and Infrastructure

Electricity access in Africa

Almost 50 per cent of the population in Africa live in rural areas with no access to electricity. Africa generates 47 GW of electricity; that is less than 0,6 per cent of the global market. Figure 3.17 shows the number of people living without electricity worldwide. Of these, 547 million people live in SSA, representing 35 per cent of the global total.³³ In many SSA countries, the access to the electricity grid is less than 1 per cent. At the same time, recent trends indicate that more than 60 per cent of the SSA population will still have no access to electricity by 2020.³⁴

There are wide disparities in access to electricity (up to 67 per cent of South Africans have access to electricity, while this figure is only 6 per cent for Malawians and 4 per cent in Lesotho). With the help of the US Department of Energy and other international communities, African

Figure 3.17 Africa's electricity accessibility

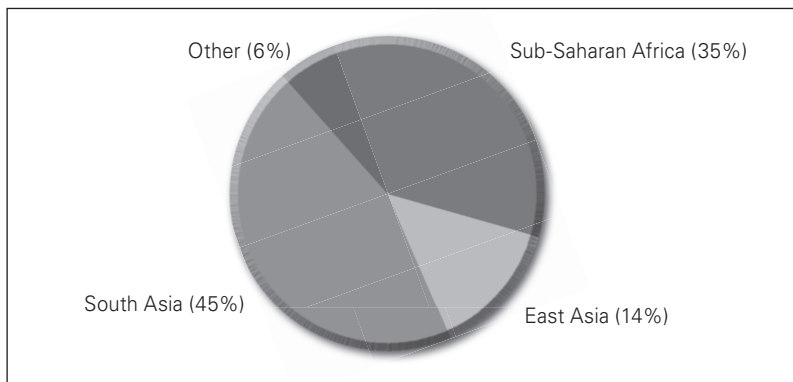


Table 3.1 Rural electrification in Africa

East Africa	• With more than 80 000 systems installed and nearly 20 000 annual sales, Kenya has the highest penetration rate of PV systems in the world.
North Africa	• Morocco planned to raise the rate of electrification in rural areas from 21% in 1994 to 60% in 2003. • The government planned to electrify 550 000 rural households by spending an estimated \$153 million/year to expand power networks to remote and rural areas. • From 1996 to 1998, the country's rural electrification programme extended power to 2 728 villages representing 284 000 households.
Southern Africa	• Zimbabwe planned to use solar power to electrify more than 500 districts and rural service points. Each site would receive solar systems with generation capacity of either 100 or 500 kW.
West Africa	• The government of Burkina Faso planned to have completed electrification in 48 of the estimated 350 communities in the country by 2010. • The Côte d'Ivoire government announced in early 1999 that, with the addition of new generation facilities, power would be provided to 200 villages/year. • The government of Ghana is committed to bringing electric service to every community of 500 or more people by 2020. The National Electrification Scheme was planned to proceed in six five-year phases from 1990 to 2020. • Senegal planned to increase electricity availability by 44% in towns and 95% in rural areas by 2004. Under its Programme 3000, all Senegalese villages with a population of 3 000 or more inhabitants will be electrified when the project is completed.

countries have launched several rural electrification programmes. Samples of these programmes are presented in Table 3.1.³⁵

Electricity Infrastructure in Africa

Africa's largest infrastructure deficit is found in the power sector, including generation capacity, electricity consumption, and security of supply. It is a fact that Africa provides only a fraction of the electricity service found in developing countries. The 48 countries of sub-Saharan Africa (with a combined population of about 800 million) generate roughly the

same amount of power as Spain (with a population of 45 million),³⁶ in addition to very low access rates to electricity: 3 to 40 per cent (excluding South Africa).³⁷

As previously mentioned, due to the fact that the natural resources in Africa are not evenly distributed, regional cooperation and integration through energy pooling and cross-border energy trading would help economic development on the continent. This can be achieved through promoting cross-border interconnection of electricity grids and gas pipeline networks and the joint development of new electrical generation projects.

On the other hand, interconnecting alternating current (AC) networks will increase the complexity of the system to such an extent that it may affect the reliability, security, and stability of the system, due to the interactions of equipment and control actions. Therefore, it is important to have a balanced renewable energy strategy which takes into account future integration with small, midsize, and large regional projects.

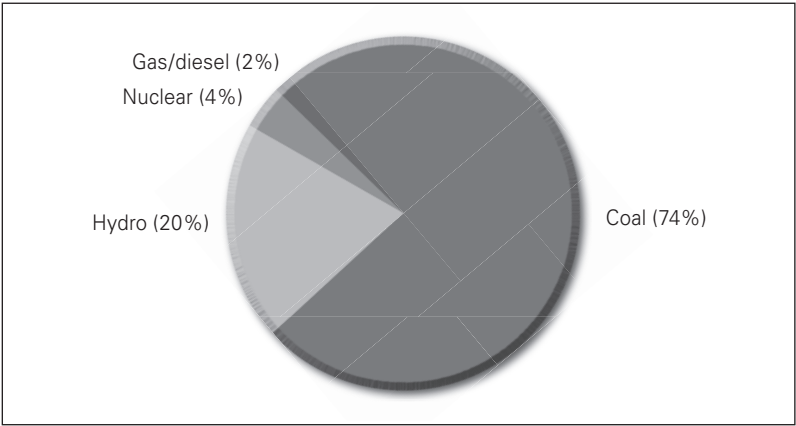
Because of this, many arguments have been put forward for the creation of power pools in Africa:³⁸

- Using ‘economies of scale’: the creation of power pools in Africa will stimulate larger and regional power markets to reduce the risk of investment in the African power sector and to support a broad section of customers.
- Increasing system reliability and security of supply through interconnected power systems: for example, a number of member countries in the Southern African Power Pool (SAPP) have lost power generation for a short while due to a system fault and were supported by their neighbours through emergency support agreements within the pool.
- Taking advantage of the generation mix to mitigate the effects of drought in the pool.
- Supporting a reduction in planning and operating reserves, and improving service delivery to customers.

Map 3 on page 95 and Map 4 on page 96³⁹ show the SAPP, WAPP, CAPP, NAPP and EAPP power pools with their interconnections in the continent.⁴⁰

Figure 3.18 shows the generation mix in Africa’s power pools and the scale of production as a percentage of the installed capacity.

Figure 3.18 Africa’s generation mix, installed capacities, and production percentages

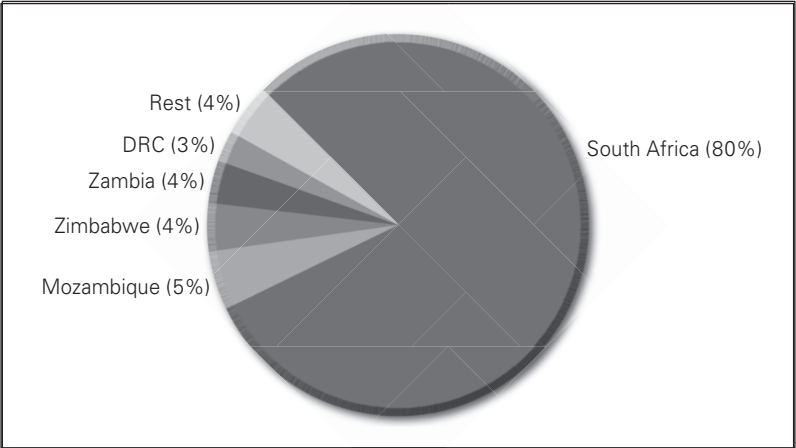


The South African Power Pool

Southern Africa embraces the SAPP, which includes 12 member utilities from the SADC countries: Angola, Botswana, the DRC, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe.⁴¹

The SAPP was created with the primary aim of providing reliable and economical electricity supply to consumers of each of the SAPP

Figure 3.19 Generation mix and contributions in the SAPP



members.⁴² The SAPP is a good example of a cooperative pool that is now becoming a competitive power market. Figure 3.19 shows the generation mix in 2009 and Figure 3.20 shows the contributions in SAPP. Map 5 on page 97 and Map 6 on page 98 present the transmission projects in the SAPP.⁴³

The Eastern African Power Pool

East Africa embraces the EAPP, which includes Burundi, Djibouti, the DRC, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda.⁴⁴ As it accounts for 70 per cent of power demand within the EAPP, Egypt is considered to be the driving force. The EAPP also covers part of the Nile Basin Initiative and includes Tanzania and the DRC that are also members of the SAPP.⁴⁵

Statistics show that the bulk of the EAPP countries' power supply is provided by hydro. That is why the EAPP currently faces a power supply crisis due to the significant decrease of water levels in rivers and lakes. In addition there has been a lack of investment in power generation since the early 1980s. In order to overcome this situation, the EAPP has taken steps towards the development of infrastructure in generation, transmission, and cross-border interconnections. Ethiopia, with its abundant hydro resources, is playing a significant role. It planned to increase hydropower projects (total additional capacity of about 3,6 GW) by 2015 from the current installed capacity of 810 MW.⁴⁶

Table 3.2 provides the planned generation projects in EAPP. Table 3.3 and Figure 3.20 show the planned interconnection projects within the EAPP.⁴⁷

The Central African Power Pool

The countries of Central Africa created the CAPP in April 2003. It is a body of the Economic Community of Central African States (ECCAS) and is headquartered in Brazzaville, Republic of Congo.⁴⁸ It comprises Angola, Burundi, Cameroon, Central African Republic, Congo, Gabon, the DRC, Equatorial Guinea, Rwanda, São Tomé and Príncipe, and Chad. Rwanda plays the role of an active member.⁴⁹ See Map 3 on page 95.

The vision of the CAPP is to use the enormous central African hydro-electric potential. This potential is estimated at more than 650 TWh/year (52% of all the African potential), enough to satisfy all of Central

Table 3.2 Planned generation projects in the EAPP

Title of the project	Installed capacity (MW)	Proposed commissioning date	Countries involved
Kabu 16	20	2012	Burundi
Rusizi 3 (share of each country)	47,8 (15,9)	2015	Burundi, DRC, Rwanda
Rusumo Falls (share of each country)	61,5 (15,3)	2014	Burundi, Rwanda, Tanzania
Olkaria 3 (geothermal)	35	2008	Kenya
Kiambere rehabilitation	20	2008	Kenya
Kindatuma 3	20	2008	Kenya
Ewaso Ngiro	220	–	Kenya
Low Grand Falls	140	–	Kenya
Gililbe III(1,2)	1 800	2012	Ethiopia
Gililbe 2	420	2008	Ethiopia
Beles	420	2009	Ethiopia
Takeze	300	2008	Ethiopia
Halele Warebesa	300	2014	Ethiopia
Chemoga Yeda I & II	280	2015	Ethiopia
Bujagari	200	2012	Uganda

Table 3.3 Interconnection projects in the EAPP

Title of the project	Length of the line (km)	Voltage level (kV)	Countries involved
Ethiopia– Kenya	1 200	400	Ethiopia, Kenya
Uganda–Kenya	172	220	Uganda, Kenya
Rwanda–Burundi	103	110	Rwanda, Burundi
Upgrade of Burundi–DRC	79	110	Burundi, DRC

Table 3.4 Generation capacities in CAPP

Countries	Installed capacity (MW)	Distribution (%)
DRC	2 502	52,2
Cameroon	902	18,8
Angola	665	13,9
Gabon	414	8,6
Others	311	6,5

Africa's demands for electricity, through systems interconnection and an open market for electric energy exchanges. Table 3.4 shows the CAPP installed capacity and generation.⁵⁰

The West African Power Pool

The WAPP was founded in 2000, as a cooperation between the national electricity companies in West Africa under the sponsorship of the Economic Community of West African States (ECOWAS).⁵¹ It is responsible for managing the cooperation between the national electric utilities by designing the framework of cooperation, regulating the power pooling and determining the level of participation of each utility. Therefore, WAPP manages the execution and report of studies and information sessions related to electricity production and transmission in the region. It also manages the financing and implementation of the projects identified as a result of its analysis.⁵² The WAPP divided the ECOWAS member states into two zones (see Map 4 on page 96):⁵³

- Zone A comprises Nigeria, Niger, Benin, Togo, Ghana, Côte d'Ivoire, and Burkina Faso, and
- Zone B comprises Mali, Mauritania, Senegal, Gambia, Guinea, Sierra Leone, Liberia, and Guinea-Bissau.⁵⁴

The WAPP has a capacity of 1 GW generation, supplied by small privately owned diesel generators at peak demand. Taking into account the regional drivers of electricity demand (economic growth, population growth, increased access to electricity and improved satisfaction of suppressed demand), the current projection for electricity demand in the region is expected to grow at more than 7 per cent/year. Therefore, this

Figure 3.20 Interconnection projects in the EAPP

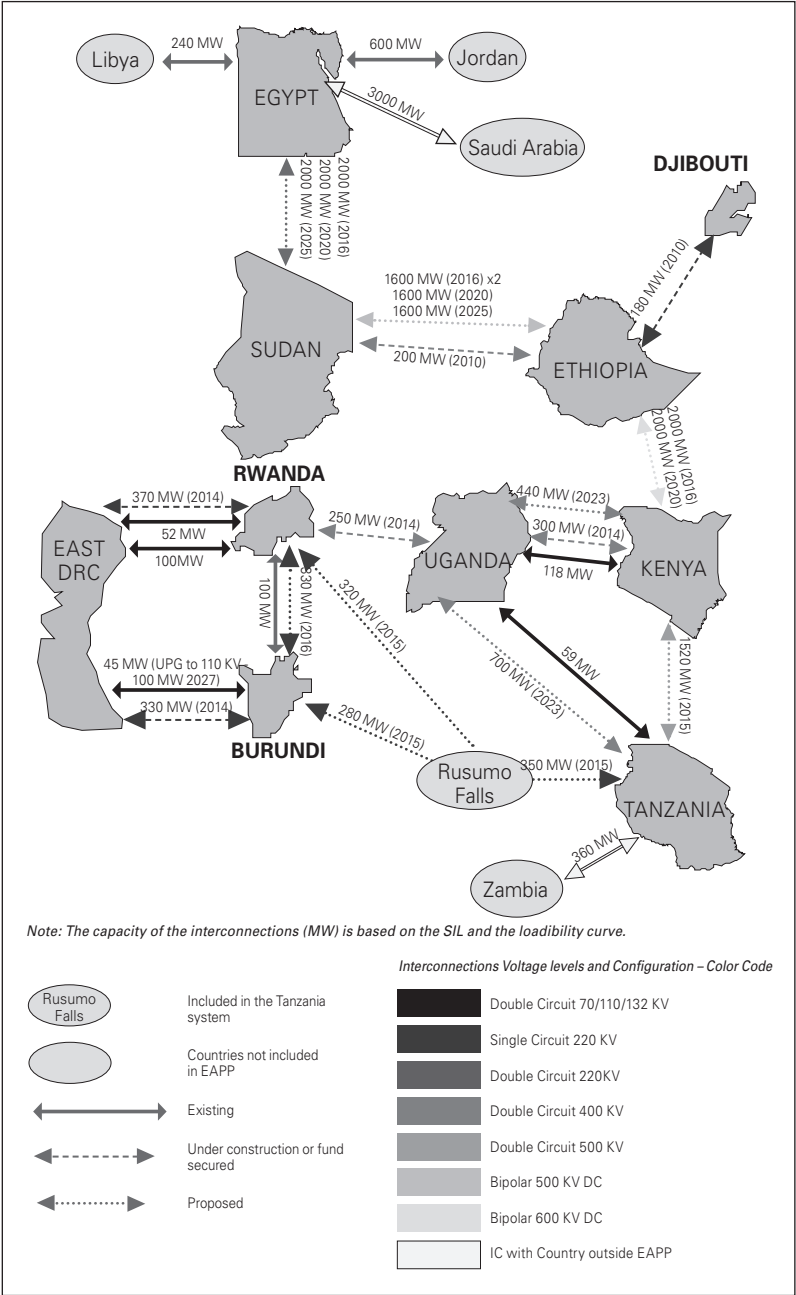


figure will result in a regional peak power demand exceeding 22 GW by 2020. Thus, medium- to long-term generation projects will also be considered to add more than 30 GW to the grid. As a result, the annual average planned new generation capacity is about 3,327 MW. In general, most of the countries in West Africa have small power utilities. However, the Ghanaian and Nigerian utilities have installed generating capacity of more than 1 GW.

Map 7 on page 99 shows the power grid and interconnections in the WAPP region. There are major interconnection projects under development, such as:

- OMVG – 2 000 km of 225 kV transmission lines and associated hydropower projects; the 240 MW Kaléta hydro plant will be the first, and
- OMVS – hydropower projects at Félou (62 MW) and Gouina, and expansion of the existing 225 kV transmission system in Senegal.

North Africa

In general, the North African countries – Algeria, Egypt, Libya, Western Sahara, Morocco, and Tunisia, do not face energy crises.

In this region, the thermal generation counts for 90 per cent; hydropower generation is almost 9 per cent, and the renewable power generation is approximately 1 per cent. Table 3.5 describes the yearly electricity consumption in 2008, the per capita consumption, the installed capacity and the net generation for North African countries (excluding Mauritania). Figure 3.21 shows the installed capacities split among the main primary energy sources.

The amount of installed capacity in Egypt approximately equals the installed capacity of all the other four countries put together. Egypt and Morocco are the only two countries with a significant amount of hydropower generation capacity (12.4% for Egypt and 32.7% for Morocco). However, it is approximately 1,9 per cent for Tunisia and 2,7 per cent for Algeria. Libya's installed capacity consists entirely of thermal plants. A small share of renewable energy is used in Morocco (2,2%), Egypt (1,3%), and Tunisia (0,6%). New generation capacity in Algeria, Libya, and Tunisia is based on natural gas; while Morocco depends on oil and coal, and Egypt relies on natural gas and light fuel oil.⁵⁵

By 2018, the total additional approved capacity of all five countries (excluding Mauritania) will reach 45 GW, of which 24,3 GW is in Egypt,

10,4 GW is in Algeria, 4,7 GW is in Libya, 3,8 GW is in Morocco, and 1,9 GW is in Tunisia. Another evaluation of estimated planning for the nuclear option of 1 GW in Egypt and 950 MW for Morocco is scheduled for 2020.⁵⁶

Table 3.6 shows the interconnection between countries in North Africa (excluding Mauritania).⁵⁷

Scaling Up Renewable Energy in Africa

Over the past decades in Africa, the gap between the supply and demand energy balance has widened drastically. Owing to poverty and recent high and volatile oil prices, poor energy infrastructure is in place. These facts result in the continuation of a lack of access to basic energy. Therefore, renewable energy has emerged as a viable alternative in most places in Africa to effectively contribute towards addressing Africa's energy challenges. However, current efforts to expand renewable energy implementation in Africa are still focused on removing barriers, so that much more can be done.⁵⁸

Renewable energy technologies, with their modular nature and availability at the local level, are considered to be an added value to contribute to sustainable development, and assist in increasing access to energy services to most rural areas. For small-scale renewable energy applications, local affordable energy to the poor can be obtained for both rural and urban applications. For large-scale renewable energy applications many positives can be achieved, such as diversifying energy supply, reducing energy imports, and helping to achieve local and global environmental goals.⁵⁹

Current Renewable Energy Applications in Africa

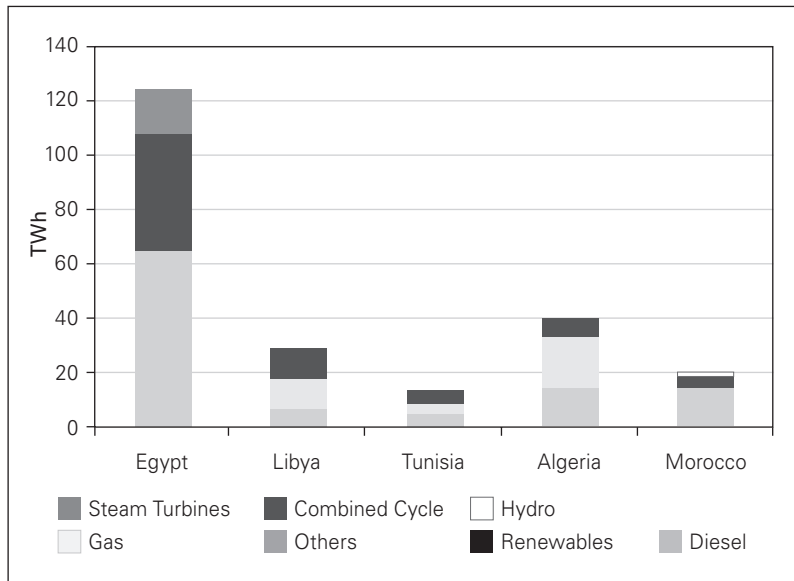
Large-scale renewable energy applications

Studies have showed that the total hydropower potential for Africa is equivalent to the total electricity consumed in France, Italy, Germany, and the United Kingdom. For example, in the DRC, the potential for hydropower generation from the Inga River is estimated to be about 40 GW. This figure accounts for more than 50 per cent of Africa's hydropower potential.⁶⁰

Biomass energy can be used to provide process heat, liquid fuels production, heat cogeneration, gasification, biogas production and solid

Table 3.5 Countries' consumption, installed capacities and generation

Net generation (TWh)	Installed capacity (MW)	Consumption (TWh/yr)	Country
125,1	22 848	106,6	Egypt
28,7	6 196	16,8	Libya
13,7	3 316	11,8	Tunisia
40,0	8 503	32,6	Algeria
20,3	5 292	21,7	Morocco
227,8	46 148	189,5	Total

Figure 3.21 Electricity generation in 2008

fuel production. For example, cogeneration from agriculture waste contributes as much as 40 per cent of Mauritius's total generated electricity.

Solar energy projects are limited in Africa due to cost constraints. However, studies show that Africa has great potential for concentrated solar thermal power (CSP) generation from desert areas such as the Sahara and Namib. South Africa has a 0,5 MW CSP plant, while Egypt plans to install CSP of 300 MW by 2020.⁶¹

Table 3.6 Regional interconnections

Year of operation	Thermal limit (A) winter	Voltage (kV)	Type AC/DC	To country	Country
1988	640	225	AC	Morocco	Algeria
1988	640	225	AC		
2006 (2010)	1 720 x 2	220 (400)	AC		
1984	510	150	AC	Tunisia	
1984	640	225	AC		
1952	380	90	AC		
1956	510	90	AC		
2005 (2010)	1720	220 (140)	AC		
1988	640	225	AC	Algeria	Morocco
1988	640	225	AC		
2006 (2010)	1 720 x 2	220 (400)	AC		
1996	730 MW	400	AC	Spain	
2006	960	400	AC		
1956	510	90	AC	Algeria	Tunisia
1984	510	150	AC		
1984	640	225	AC		
1952	380	90	AC		
2005 (2010)	1 720	220 (400)	AC		
2003	2 x 620	220	AC	Libya	
2003	620	220	AC		
1998	2 x 630	220	AC	Egypt	Libya

Wind energy in Africa is still struggling due to lack of precise information about the wind power generation potential in Africa. By early 2008, Africa had installed approximately 476 MW of wind energy generation capacity in Morocco, Egypt, Tunisia, South Africa and Ethiopia. Egypt

has added more wind farms and plans to add 7 200 MW by 2020 to supply 12 per cent of its generated power.

Geothermal energy generation has been developed only in a few countries in Africa. Kenya installed up to 127 MW that accounts for about 17 per cent of the country's power supply. Recently, Ethiopia installed 7 MW, and several plans at different stages in Uganda, Tanzania and Eritrea are in operation.

Small-scale renewable energy applications

Small hydropower applications (less than 10 MW) can be used to supply energy to remote communities. Other micro-hydropower applications are in place in many African countries to generate electricity to villages.⁶²

Solar home application in the household sector is the most common use of these applications. South Africa and Kenya installed capacities of solar PV applications of 11 000 and 3 600 kWp respectively. Other CSP applications are used for water heating and solar cookers. Solar heater applications have payback periods between three and five years.

Barriers to Renewable Energy Development in Africa

Even though renewable energy can contribute to solving the African energy problem, major barriers hindering the spread of renewable energy in Africa have to be overcome. These barriers can be classified as:

- policies and institutional regulations,
- information and technical capacities, or
- financial.

Policies, regulations and institutional frameworks

Consistent and harmonised policy and regulatory frameworks are necessary to integrate renewable energy in Africa. Unfortunately, these frameworks do not exist. Furthermore, in many African countries, a clear governmental adoption pathway to lead to consistent policies and regulations is absent. These factors hinder the involvement of private and industrial sector investments in renewable energy applications in Africa. However, a few African countries such as Kenya and Zimbabwe

have removed tax on PV systems. Egypt is initiating tax redemption on imported renewable energy equipment.⁶³

Furthermore, current policies allocate relatively low budgets to develop renewable energy projects (less than 3% of total public expenditure). Only a few suitable policies have been developed in North Africa and Southern Africa.⁶⁴ However, their impact is still weakened by a lack of existing enforcement mechanisms in these countries.

Information and technical capacity

The unavailability of accountable, accurate, well-organised and stored renewable energy resource data is considered to be the major technical barrier to the development of technologies such as solar and wind technologies.⁶⁵ Poor technical and imported equipment maintenance skills and after-sales service in Africa affect the development of all renewable technologies.

Financing and investments

In 2007, according to latest studies, worldwide investments in new renewable energy capacity, manufacturing and R&D reached \$100 billion. However, Africa was only able to receive less than US\$1 billion for the renewable energy sector – excluding large hydro.⁶⁶ Also, Africa's share of foreign direct investment (FDI) was about 10,6 per cent of the \$500 billion inflows into developing countries.

Therefore, due to the existing weakness of African governmental support, the private sector, banks and lending facilities lack an enthusiasm in investing in renewable energy applications. For example, the African Development Bank (AfDB) has estimated that the total investment required to implement universal access to reliable and increasingly cleaner electric power in all the 54 countries in Africa by 2030 is \$547 billion.⁶⁷ This huge investment averages out at approximately \$27 billion/year, while, the total funding for the sub-Saharan African energy sector has averaged only approximately \$2 billion/year.

Thus, the private sector remains a small player at the end that implements small-scale renewable energy applications only. Meanwhile, the bulk of private-sector financing is non-local and mostly derived from international (external) financing organisations and thus guaranteed by beneficiary African governments.

Financing Renewable Energy in Africa

Several financial institutions are currently investing/lending money into the renewable energy sector. In 2008, investment in new renewable energy power generation capacity (including large hydro) exceeded investment in fossil-fuel generation. The global investment in this sector increased to reach \$155 billion in 2008 compared to \$22 billion in 2002.⁶⁸ However, due to the world finance crisis in late 2008, this increase has been affected.

Although financing approaches for investments in renewable energy are similar to those for any other investments, certain characteristics have to be taken into consideration. These characteristics have to be added to the basic financial analysis. Some of these factors are the influence of policy and regulation on the viability of an investment, and counting the legal basis and durability of any local subsidies, grants, tradable certificates or tax credits (for all/some of renewable technologies). Also, financial institutions make a return which is proportional to the expected risks that they may face, and they set up legal means for minimising/managing these risks in investing in renewable energy projects.

Investment

It is necessary to determine the overall costs of expanding the power sector based on well-defined strategies for generating, transmitting, and distributing electricity in response to demand increases. Also, there should be a special focus on the dominant players in each power pool. For example, South Africa accounts for 80 per cent of overall power demand in SAPP; Egypt is responsible for 70 per cent in EAPP; Nigeria represents 67 per cent in WAPP; and the Republic of Congo and Cameroon account for a combined 90 per cent of power demand in CAPP.

The overall costs for the power sector in Africa between 2005 and 2015 are an estimated \$47,6 billion/year: \$27,9 billion for investment and \$19,7 billion for operations and maintenance (O&M).⁶⁹ Almost half of the investment cost is for the development of new generation capacity and another 15 per cent for rehabilitation of existing generation and transmission assets. Table 3.7 shows the investment and spending requirements in the different African power pools.⁷⁰

Table 3.8 shows the amount of money spent on the electricity sector and infrastructure from different identities.⁷¹

Table 3.7 African power sector spending requirement (\$ million), 2005–2015

Pool	Total expenditure	Total O&M	Total investment	Investment		
				Rehabilitation	New generation	New T&D
CAPP	1,386	159	1,227	76	860	292
EAPP	15,004	6,807	8,198	485	5,378	3,334
SAPP	18,401	8,359	1,004	2,554	4,544	2,944
WAPP	12,229	4,049	8,238	1,010	3,527	3,701
Total	47,078	19,374	27,705	4,125	14,309	10,271

Table 3.8 Africa's financing instruments for locally sourced infrastructure financing in (\$ millions)

	Bank loans	Government bonds	Corporate bonds	Equity issues	Total
All infrastructure	11 282,7	801,1	7 389,4	55 944,9	75 418,1
Electricity	2 694,7	0	3 672,8	3 268,4	9 635,9

The global transition to renewable energy will require huge investments in national/local energy infrastructures in every country over the coming decades. These investments will need funds from both the public and the private sectors. Furthermore, they will have to take many forms, including:

- financial incentives from government,
- loans and capital investment from banks, private investors, venture capital funds and communities, and
- new innovative markets that contribute to the benefits of renewable energy and energy efficiency.

Financing sources will include venture capital, share raised capital, energy bill charges (public benefits or lines charges), financial institutions, community development funds and general tax revenues.⁷²

Three financing issues require consideration in any renewable energy strategy.⁷³

- Firstly, sources of financing – loans, investment capital, environmental markets, international facilities and partnerships.
- Secondly, policies that influence increased investment – financial incentives, standing offers, market transformation, training and infrastructure development.
- Thirdly, financing mechanisms – micro-finance, on-bill payment, leasing/rental and local improvement charges.

Renewable energy project financing is a hazardous process for developers. They need to consider various aspects, such as technical, contractual and permissions. In addition to those aspects, small projects face difficulties in attracting the attention of lenders or investors. Furthermore, as project lenders will have priority access to a project's cash flow, the shareholders may not receive much of a return on the project investment until the project debt is paid off.⁷⁴

The chosen method of raising project finance directly affects how the whole project will be developed. Therefore, at an early stage of planning the project, the developers should consider which financing options are available; this will accordingly affect how the whole project is structured. Although every project is different, there are generally five possible ways of financing a renewable energy project:

Internal company reserves, personal reserves or funds from business associates. (However, for very small projects, sufficient personal reserves would be enough to meet the total project's cost.)

Bank loans secured against other parts of the developer's business or major assets ('on balance sheet finance') or personal guarantees linked to developer-owned property.

Co-development of the project with a financially strong joint-venture partner, who is more readily able to facilitate the necessary finance.

Limited recourse project financing, whereby bank loans are secured largely against future cash flows rather than just physical assets; these involve a series of complex contractual arrangements.

Leasing, which is rarely available, gives the lessee use of the project in return for regular payments to the lessor, who remains the legal owner. Tax allowance benefits claimable by the lessor (lessor) are passed on to the developer by way of reduced lease payments. Operating leases, being short term and cancellable, are unlikely to be used to finance

major equipment in a renewable energy project. Finance leases are non-cancellable and normally cover the whole of the project's economic life.

Finally, it should be considered that financing any project is time consuming and complex. Also, developers must have dedication and the will to overcome problems and setbacks. The developer must consider the method of financing early on in the project development process, drawing, where necessary, on professional financial and legal advice.

Conclusions and Recommendations

Based on the abovementioned facts about Africa, it is clear that the infrastructure and reserves cannot meet the demands of this continent. African energy resources have the full potential to overcome the continent's energy deficit. However, energy reserves, production, and consumption are poor in comparison with global figures.

African countries have substantial renewable energy resources; however, they face many challenges to benefit from them. The major challenge is Africa's ability to contribute to sustainable development.

Proper selection of renewable energy technologies is essential; therefore it is critical to develop the local markets and domestic capacities to absorb these technologies. For that, there should be a special focus on increasing the participation of the private sector within an enabling and conducive environment. Also, the development of human and institutional capacities to deal with the manufacturing, operation, and development of renewable energy technologies is essential.

In this context, policy makers are required to set rational targets for the contribution from renewable energy to Africa's energy mix and to invite all developers to assist the continent to meet such targets. For example, the current annual estimates of non-large-scale hydropower investment flows to renewable energy development in Africa are below \$1 billion, which will be increased to \$10 billion over the next five years (2009–2014).⁷⁵ Policy makers could set a similar target to request renewable energy investment, and ask the African Union Commission (AUC) and other developers to draw up a plan on how to reach this target and integrate investment programmes into already existing partnerships, such as the Africa-EU Energy Partnership. Moreover, they should call upon international financing institutions to set accessible financing techniques to encourage local and international private sectors to finance renewable energy projects. These techniques should take into account the local context with respect to sources and patterns of income, attitudes to

borrowing, availability of micro-credit agencies, and ability to repay over long- and short-term periods. Moreover, they should also be for both end-users and suppliers and should be supported by past experience.

Risk reduction is another important practice for developers of renewable energy. Delays, technical risk, resource uncertainty (both in quantity and price), renewable energy premiums, cost overruns, sales price/volume, maintenance costs and others are all risk factors that need to be identified and managed.

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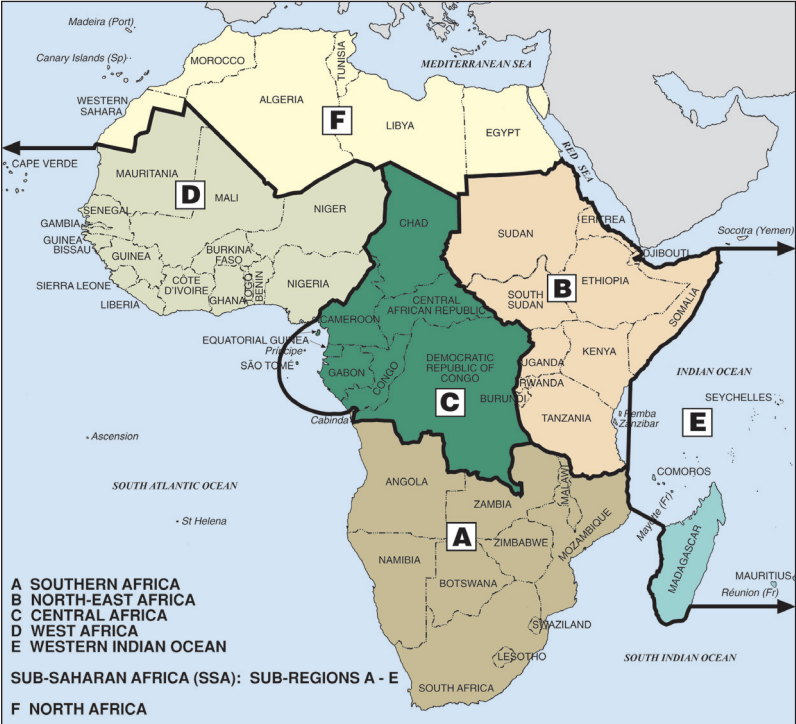
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Map 1 Africa's renewable energy mix¹



Map 2 Africa’s districts²

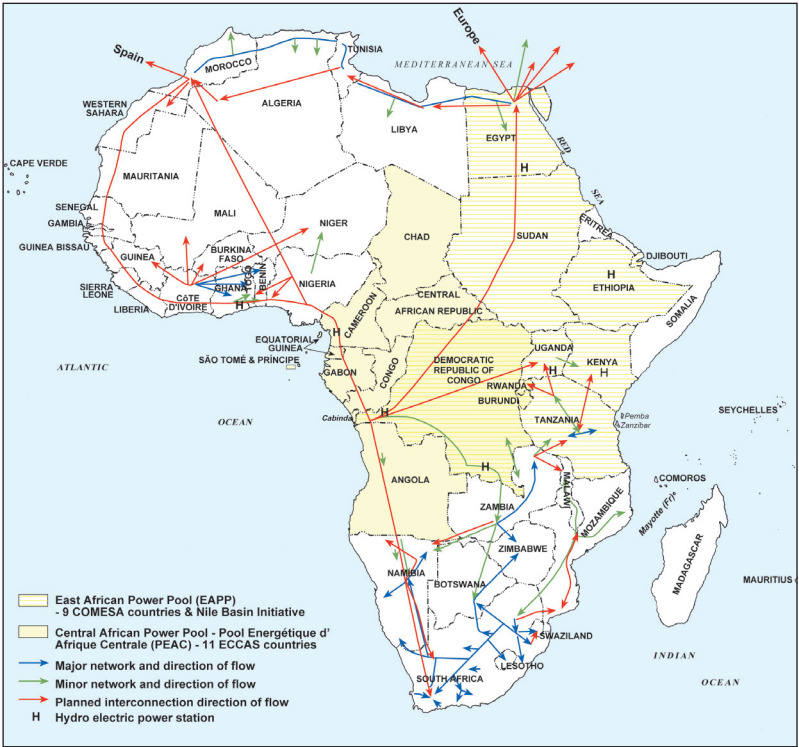


COMPARATIVE SIZE OF REGIONS	AFRICA	SOUTHERN AFRICA	NORTH-EAST AFRICA	CENTRAL AFRICA	WEST AFRICA	WESTERN INDIAN OCEAN	NORTH AFRICA
Independent countries	53	10	11*	8	16	4	5
Area (million sq km)	30	6	6	5	6	0,6	6
% of Africa	100	20	20	18	20	2	20
Population mid-2010 (million)	967	131	259	105	291	23	158
% of Africa	100	14	27	11	30	2	16

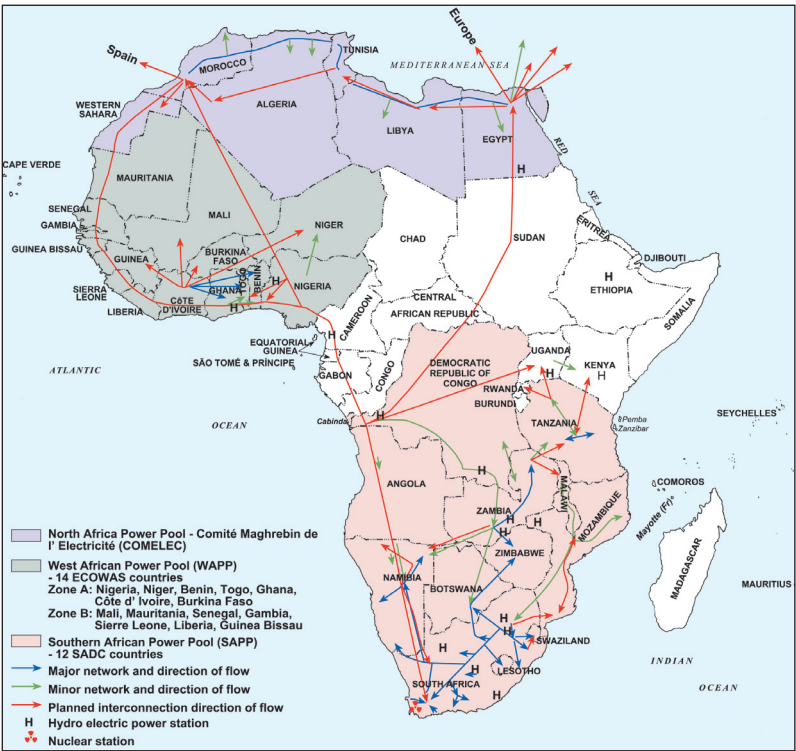
Note: In addition to Sub-Saharan and Sub-Equatorial Africa the continent can be subdivided into six smaller, but still vast geographical regions, shown here. As there is no consensus as to what constitutes the geographical sub-regions of Africa, the sub-divisions on this map are presented as the compiler’s interpretation, based on common natural features, economic ties, transport links and cultural affinities.

* South Sudan became independent on 9 July 2011.

Map 3 The EAPP and CAPP (PEAC)³



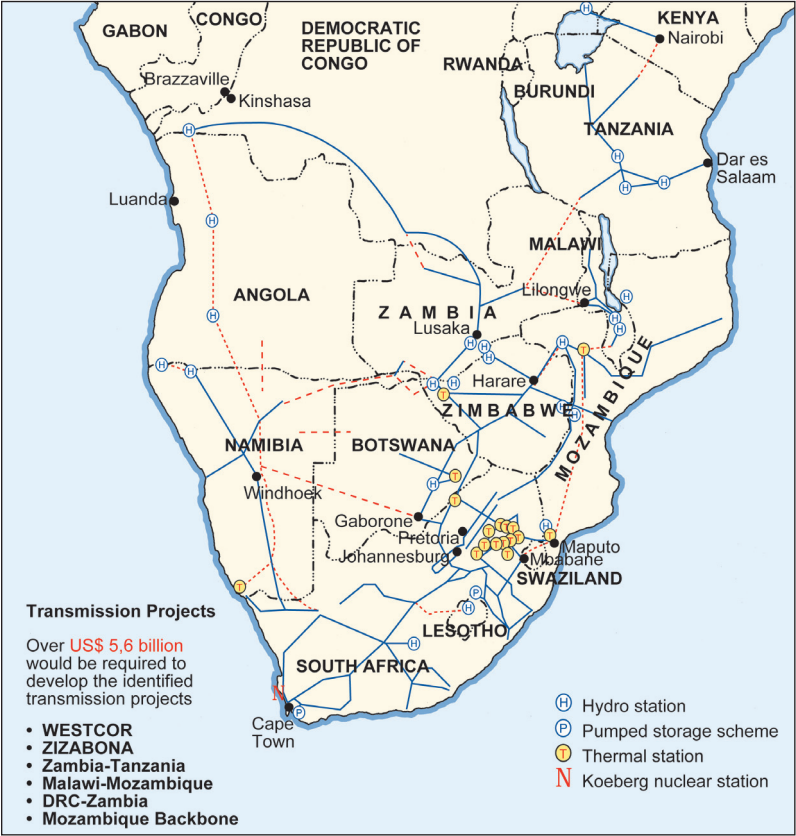
Map 4 The NAPP (COMELEC), WAPP and SAPP⁴



Map 5 Transmission projects in Africa⁵



Map 6 Transmission projects in Africa⁶



Map 7 West African Power Market Development Project, HV Transmission Networks and Prospective Interconnection Projects (Phase 1)⁷



Notes and References

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Human capital requirements for sustainable renewable energy production

Timothy Simalenga

Introduction

Human resource development (HRD) refers to both formal and informal activities that will enhance the ability of individuals to reach their full potential in a particular discipline. By enhancing the skills, knowledge and abilities of individuals, HRD will improve the productivity of people in their areas of expertise – whether these are in formal or informal settings. Improved skills increase productivity in a country that will in turn enhance economic development, as well as social development.

The major concern therefore is to accelerate development at all levels so that there is a match between supply and demand for human resources. HRD is about taking purposeful action to increase the aggregate levels of skills in the workforce so that we can maximise opportunities for individuals, thereby benefiting the industry and society as a whole.¹ HRD is built on two basic principles:

- that the human being is at the centre of all targeted development activities, and
- that human resources are an essential means of achieving meaningful economic, social and overall development goals.

Renewable energy technologies have become one of the most dynamic and rapidly changing sectors of the global energy economy. The ever-increasing

advocacy coupled with targeted growth in the production and use of bioenergy in the past few years has attracted interest from farmers, technologists, scientists, policy makers and investors around the globe.² While it is essential to acknowledge that renewable energy and energy efficiency promote rural economic development, a good environment, and improved health and welfare, human capital is key to achieving these goals.

Renewable energy and energy efficiency have the following possible positive outcomes:

- rural economic development
- a clean environment
- energy independence
- improved health and welfare, and
- job creation.

In order to contribute to sustainable renewable energy development, human capital development at all levels – from scientists and policy makers to entrepreneurs and end-users – is crucial in shaping the bioenergy industry in developing countries. Most developing countries and their associated multilateral institutions acknowledge the need to pay more attention to the role of HRD in supporting national economic growth and renewable energy-related development programmes.³ This acknowledgement of the importance of HRD has been illustrated by the response of the United Nations (UN), which formally included HRD on its agenda through Resolution 33/135 of 1978, following discussions on the subject over many years.⁴ The 1989 General Assembly Resolution 44/213 declared:

Human resources development is a broad concept...requiring integrated and concerted strategies, policies, plans and programmes to ensure the development of the full potential of human beings...so that they may, individually and collectively, be capable of improving their standard of living.⁵

Human capital development in Africa will have to focus on the following key areas:

- technologies and processes
- policy and socio-economic (including climate and environmental) issues
- financial and project management issues
- maintenance of and repairs to renewable energy equipment, infrastructure and operations, and
- monitoring and evaluation.

Overview of Existing Training Needs and Skills Development

The renewable energy industry, broadly defined to include biomass, geothermal, hydropower, solar, wind and tidal wave energy, has experienced double-digit growth rates year after year for several decades.⁶ Despite the difficult global economic climate in 2008 and 2009, the renewable energy industry's expansion has continued, albeit at a slower pace. Looking ahead, virtually every report about the broader energy sector reinforces the need for a fundamental transition of the world's use of cleaner and more renewable energy sources.⁷

The report in 2010 highlighted the fact that approximately 2,3 million people worldwide work either directly in renewables or indirectly in supplier industries.⁸ It has also been estimated that the renewables using 'wind power' industry employ approximately 300 000 people; the solar photovoltaic (PV) sector has been reported to account for an estimated 170 000 jobs, whereas the solar thermal industry accounts for at least 624 000 jobs; and more than one million jobs have been created in the biomass and biofuels sectors.⁹ These jobs are in areas as varied as project development, turbine component manufacturing, construction and installation of wind turbines and solar panels, solar thermal operations and maintenance, as well as in marketing services of these renewables.

By the year 2030, it has been projected that the renewable energy industry could employ 6,3 million people globally, with as many as 2 million in the US alone.¹⁰ Moreover, if one includes expected retirements from electric utilities and oil and gas companies, 'conventional energy' will increasingly be in competition with 'green energy' for a relatively finite pool of human capital. The most severe labour shortages are expected in the main energy workforce, such as in production, installation, repair and maintenance, construction industry, transportation and service jobs. These examples show that this trend will continue to play a major role in reshaping the energy infrastructure and HRD across Africa and the globe.

Therefore, human capital development will have to be taken seriously if Africa is to have any chance of expanding its use of renewable energy. Priority action areas which have been proposed include the assessment of specific education and training needs in the renewable energy disciplines, and the capability of existing institutions to meet these needs. However, attention will also be given to new areas which are ready to be introduced in a specific country. People already in the workforce will

need to be retrained, especially in new technologies and in the repair and maintenance of those renewable energy products which are new in the market. Professional trainers and educators, including university and college staff, may need further technological training appropriate to their disciplines, so that local educational institutions can better contribute to the needs of and solutions to renewable energy problems in a particular country.

Various approaches can be used in HRD in the renewable energy sector. These include the following main categories:

- professional education and training (for BSc graduates and above)
- technical training (for certificate and diploma graduates, including artisans)
- marketing staff and promoters of renewable energy (including management and mass media), and
- policy and strategic planners in the energy sector.

Renewable energy education and training must have both long-term and short-term goals. In the short term, the main goal is to retrain specialists already in the workforce. These may include: policy makers, energy planners, educators and trainers, artisans and technicians, field workers, industrial and commercial personnel, and other agricultural and energy professionals. End-users will be re-educated through targeted awareness campaigns.

In the long term, the goal is to educate and strengthen the skilled manpower, including specialists at all levels in all areas and within the scope of renewable energy engineering. The training should include an appreciation of how the new technologies will fit into the fields they intend to work in. The above goals require many different kinds of approach and educational effort. An added value is to enhance continent-wide employment, which can be achieved through the development of new industries for manufacturing and producing spares. New consumers for the new products will be created by this approach of introducing, developing and marketing the renewable energy industry.

Long-term Education and Training Strategy for Renewable Energy Engineers and Technicians

Education and training is a key factor in assuring the sustainable implementation of renewable energy technologies.¹¹ There is a niche for

renewable energy education throughout the learning phases and the education process, from primary to the tertiary level. Human capital is required in the areas of production, marketing, installation and maintenance of solar and wind technologies. Priority can also be given to designing education programmes for the public on the use and advantages of renewable energy sources. There is therefore a need to identify trainers and train them at these levels, as well as a need to have well thought-out curricula and teaching and training materials.

At technical college and university level, renewable energy should be presented as part of the sustainable energy cycle. General energy issues should take into consideration and be explained in terms of the rural and urban development context. Renewable energy technologies will receive their proper attention and be placed on a par with other energy supply options without either exaggerating or underestimating their potential importance. Great care must be taken to create and modify courses and to develop educational materials for both engineers and technicians.

Challenges

As highlighted before, the lack of renewable energy experts among target groups is one of the main challenges facing the sector. Research funding and development efforts at both research centres and universities will need to be increased. At present, there is a lack of resources and underfunding by various African governments to address renewable energy issues. Some countries, such as South Africa, have, however, taken the lead through the 10-year Science and Technology grand challenges to make renewable energy one of the five pillars for developing a knowledge economy through science and technology initiatives.¹²

The challenge to meet the demands of skilled labour in Africa still remains, however, as most of the training in renewable energy is done overseas. There is generally an inadequate supply of well-resourced training institutions in most African countries, leading to a brain drain.

Specific measures to ensure that women and youth achieve their full potential as renewable energy experts are recommended. These should include the provision of scholarships and fellowships for in-country and foreign study and the exchange of students and trainers.

Human Capital Development through Formal Training

Various studies and reports on the state of skills in different countries in Africa indicate that there has been a significant increase in the demand for skilled agricultural and engineering scientists. Two main challenges face formal training: firstly, there is a general decrease in the number of students entering these science streams and, secondly, there is an imbalance between private-sector participation in capacity-building and overall government goals.

Formal training in the region

Almost all African countries have universities with faculties or colleges of agriculture which offer BSc and diploma programmes in agriculture and related engineering qualifications. A few countries – such as Tanzania, Botswana and South Africa – have centres dedicated to training engineers and technicians in renewable energy. In South Africa, efforts have been made to establish a Centre for Renewable and Sustainable Energy Studies (CRSES) which, jointly with the School of Engineering at Stellenbosch University, offers short courses and undergraduate and postgraduate studies in the following key areas:¹³

- Renewable energy systems
- Conventional energy systems
- Solar energy
- Sustainable biomass production
- Wind and hydro energy, and
- Bioenergy.

In the short term, probably the first priority is short-term targeted education and training in the form of the retraining of trainers at all levels. Training the trainers requires a starting point: foreign consultants or fieldworkers, already-trained teachers, or autodidacts. An initial overall assessment of staff training resources is necessary to begin a renewable energy education programme. The development of country-specific renewable energy experts must be treated as an ongoing process and such programmes should be adequately financed.

Major trends, issues and challenges

With the increasing demand for renewable energy technologies, new goals for renewable energy engineering education should combine the following:

- technical and scientific excellence
- economic viability
- environmental awareness
- ethical responsibility towards society, and
- learner-friendly on-the-job training to enhance hands-on skills.

Analysing a Project for Renewable Energy Training and Development

The following highlights some of the typical topics which can be used when formal training is on offer:

Examples of topics/curriculum in bioenergy:

- Bioethanol production
- Thermo-chemical conversions, and
- Biogas production/biodiesel production

Examples of topics/curriculum in renewable and sustainable energy:

- Biodiversity and sustainable agriculture/development
- Natural resources, technology and viability of renewable energies: geothermal, hydro, wind and biomass
- Solar energy and solar water-heating principles and technologies of PV cells and solar-thermal generation of electricity, and
- Future technologies: hydrogen economy and fuel cells.

Examples of topics/curriculum in conventional and renewable energy:

- The four main conventional energy sources (coal, oil, gas and nuclear)
- The use and environmental impact of each energy source
- Policy and legal framework, and
- Renewable energy systems.

Human Capital Development through Informal Training

This section discusses the need for an informal training infrastructure in Africa. It provides resources for those interested in gaining further information about renewable energy training opportunities,

Table 4.1 Checklist of issues when analysing a project for renewable energy training and development

Assets	Issues to include
Physical	Geographic location (map) Climate (focus on enterprise groups' locations) Soil and water resources Roads, paths and trails Vegetation
Social	Community inhabitants Demography Education levels History Shocks (environmental, political)
Economic	Major economic and business activities Production capacity, specialisation Predominant production and marketing systems Commercial activities Electrification Market locations Demand channels Conservation issues and natural resources
Institutional	Types of organisation in the area: farmer cooperatives, trade associations, finance banking and micro-finance, chamber of commerce Governmental structures Educational institutions Non-governmental organisations (NGOs) and other organisations operating in the area History of intervention activities in the area
Innovation trends	Introduction of new crops, livestock and processed products Change from rain-fed to irrigated production Community social fabric Banking options, increase in remittances New business opportunities Change in telecommunications, internet or cellphones

job opportunities and general knowledge. It argues that NGOs, international donor agencies and private-sector involvement in informal training are crucial in order to achieve practical and sustainable skills development.

Renewable energy technologies have a role to play in the development of rural communities in Africa. As mentioned before, where grid power is not viable, solar electricity (PV systems)¹⁴ for lighting, refrigeration,

radio and television, water pumping, telecommunication and cottage industry applications can provide a source of much-needed energy. Thousands of solar electric systems are already in place and working in Africa. Informal training and skills development, as much as formal training and skills development, are therefore crucial to sustaining these technologies.

Other advantages of the informal approach and reasons why informal training and the promotion of renewable energy technologies are necessary:

- they help to match the needs of many communities and applications
- they are locally manageable
- they create skilled jobs in rural areas
- they help to enhance rural life
- they are environmentally safe, and
- they provide communities with a local, sustainable energy source.

Building a Sustainable Human Capital through Informal Training

Efforts to build solar electric and other renewable energy infrastructure in other parts of the developing world have shown that there are prerequisites to the successful transfer of the technology to rural communities.¹⁵ These include:

- *Supported community demonstrations:* Demonstrations are important in raising awareness and creating a demand for the technology, but they need to be supported; when systems are installed where there is insufficient backup or where spare parts supply is erratic, projects almost always fail. Many successful solar and other renewable energy dissemination efforts start with practical demonstrations.
- *Awareness raising:* There is a need for a continuous process of raising awareness about both (a) solar and renewable energy in general, and (b) the need for a renewable energy infrastructure. This needs to occur at all levels, starting from governments, NGOs and donors, right down to communities and the private sector.
- *Hands-on practical training:* In order for the technology to be effectively disseminated and utilised, organised practical training needs to take place. Those who need to be trained include

installers, distributors, sales agents, artisans, technicians, community leaders and end-users.

- *Small business support:* The renewable energy industry has great potential to provide jobs in both urban and community-based enterprises. Business people need to be encouraged to invest in solar and other renewable energy technologies. Small businesses need assistance starting up, improving products and services, gaining access to information, and identifying local and international suppliers of lamps, modules, batteries and other accessories.
- *Financing of systems:* Few people and institutions can afford to buy solar systems all at once. As with grid power, solar electric power can be sold as a service or it can be financed over time. Credit enables customers to offset the high upfront cost of solar electric systems. Financing systems should be self-sustaining and should complement the development of the local renewable energy infrastructure (i.e. realistic terms and prices, the use of locally available equipment and technicians). Financing can be done through banks, existing credit institutions and energy service companies themselves.

Informal/In-service Training and Human Capital Opportunities in the Renewable Energy Industry

Scores of successful companies in Africa are now working in the renewable energy sector and, more specifically, in the solar energy field. Most of them need human capital resources and appropriate training for their staff. Table 4.2 highlights some of the potential areas for informal training.

To date most of the informal training/in-service training and awareness-raising in the region has been done by companies themselves. Some international solar PV companies (i.e. BP, Siemens and Solarex) have excellent courses and training materials for technicians and sales people.¹⁶ However, international courses do not meet the needs of Africans, as most people cannot afford to travel to attend courses in Europe and the US. There is a need for courses to be tailored to the needs of East and Southern Africa. Several local groups have begun to establish training initiatives in the region, including the Karagwe Development Association (KARADEA) in Tanzania and the Botswana Polytechnic in Gaborone.

Table 4.2 Informal and in-service training opportunities in the renewable energy industry

Training opportunity	Type of work
Installing and repairing systems	Technicians are needed to install systems for small and large companies.
Designing systems	Designers are needed to plan systems for solar companies and for rural consumers.
Marketing systems	Sales agents are needed to market systems in the rural areas.
Financing systems	Banks, credit groups and hire-purchase agencies can provide loans or terms to allow people to buy systems.
Selling equipment and spare parts	Shopkeepers can sell lights, distilled water, batteries, electric appliances, etc.
Sale of power for income and entertainment	Where there is no grid power, solar electricity can be sold for use in: • video/disco shows, • lighting for bars and shops, and • battery and cellphone charging.
Assembling and manufacturing system components	Companies and cottage industries can manufacture system components, including • solar lamps and fixtures, • battery boxes, • controls and mounts, and • electrical equipment.

KARADEA Solar Training Facility (Tanzania)

In 1993, the Karagwe Development Association Solar Training Facility (KSTF) was established to meet an increasing demand within Kagera Region and East Africa for training in solar power.¹⁷ KARADEA offers the following courses to local people who are working in rural areas:

- solar orientation
- intensive solar electric installation courses, and
- advanced solar electricity courses.

The KSTF demonstrates a variety of PV and solar equipment and maintains an up-to-date PV and Solar Information Resource Centre which

contains textbooks, product information and lists of local and international solar companies.¹⁸

Renewable energy technologies are advancing rapidly. Keeping track of research advances, shifting technologies, prices and new products is just one of the challenges. It is especially difficult for consumers and groups considering purchasing systems to decide what to buy. The consumer is at the mercy of the supplier – and the supplier is unlikely to send a potential customer to another supplier who has a less expensive or higher quality product. At the same time, the small business person has a hard time keeping up with new technologies, finding out which products are the best, or developing new products. In this absence of information, there is a need for dedicated organisations and support groups that can provide technical training and other assistance to consumers and renewable energy companies. A selection of organisations and supporting groups that have been assisting customers, designers, projects and companies are listed in the table below.

Human Resource Development for Research and Renewable Energy Development

In a survey carried out in 14 countries of the Southern African Development Community (SADC) to determine the status of agricultural research and training in the region, it was reported that human resources, in terms of numbers of agricultural scientists, are adequate in only two countries: Mauritius and South Africa.¹⁹ In terms of quality and experience, three other countries – Malawi, Tanzania and Zambia – join South Africa in having adequacy. The other 10 countries are aggregated in the scarce and very scarce categories.

Various organisations, especially the higher learning institutions and national research centres, have programmes that support research on various aspects of renewable energy. For example, the Agricultural Research Council (ARC) of South Africa is conducting research on biofuel and other renewable energy technologies. In South Africa, various institutions, such as the University of Cape Town and Stellenbosch University, are at the forefront of the development of third-generation biofuel/energy technologies.

The Department of Science and Technology (DST) of South Africa has initiated an ambitious 10-year innovation plan which seeks to address an array of social, economic, political, scientific and technological grand

Table 4.3 A selection of Africa-based solar energy industries associations, advisory groups, organisations and societies supporting informal training

Organisations	Services offered
Botswana Polytechnic Electrical Engineering Department Private Bag X0061 Gaborone, Botswana	Solar PV training courses Technical assistance
Botswana Technology Centre Private Bag X0082 Gaborone , Botswana	Technical assistance Standards Information and awareness
Energy Affairs Division Ministry of Mineral Resources and Water Affairs Private Bag 0018 Gaborone, Botswana	Technical assistance Standards Information and awareness
Energy Alternatives Africa, Ltd PO Box 76406 Nairobi, Kenya	Training Technical assistance Information and awareness Business support
Energy of Development Research Centre University of Cape Town Private Bag Rondebosch 7700, South Africa	Technical assistance Information and awareness Standards
KARADEA Solar Training Facility PO Box 99 Karagwe Kagera, Tanzania	Training Information and awareness
Madiba Electrical Brigade Private Bag 12 Mahalapye, Botswana	Training
Gilgil Polytechnic PO Box 126 Gilgil, Kenya	Training
Photovoltaic Industries Association of South Africa PO Box 10300 Rivonia, 2128 , South Africa	Trade association Standards Business support
Rural Industries Innovation Centre (RIIC) Solar Energy Section Private Bag 11, Kanye Botswana	Information and awareness

Organisations	Services offered
Solar Energy Society of Zimbabwe PO Box MP 119 Mount Pleasant Harare, Zimbabwe	Information and awareness
SADC TAU New & Renewable Sources of Energy PO Box 2876 Luanda, Angola	Information and awareness Technical assistance
Solar Energy Industries Association of Zimbabwe PO Box BW 1057 Harare, Zimbabwe	Trade association Standards Business support
Sustainable Energy Society of Southern Africa PO Box 868 Ferndale 2160, South Africa	Information and awareness
UNDP/GEF/DOE Solar Lighting Project PO Box 4775 Harare, Zimbabwe	Financing Information and awareness Standards

challenges through innovative research activities. Through this plan, five grand challenges have been identified and are designed to stimulate multidisciplinary thinking and to challenge researchers to answer existing questions, create new disciplines and develop new technologies.²⁰ The grand challenge areas as presented by the DST are:

- *The 'Farmer to Pharma' value chain to strengthen the bio-economy:* Over the next decade South Africa must become a world leader in biotechnology and pharmaceuticals, based on the nation's indigenous resources and expanding knowledge base.
- *Space science and technology:* South Africa should become a key contributor to global space science and technology, with a National Space Agency, a growing satellite industry, and a range of innovations in space sciences, earth observation, communications, navigation and engineering.²¹
- *Energy security:* The race is on for a safe, clean, affordable and reliable energy supply, and South Africa must meet its medium-term energy supply requirements, while innovating for the long term

Table 4.4 A selection of international information sources/support groups

European Photovoltaic Industry Association Avenue Charles-quint 124 B-1080 Brussels, Belgium	Tel: 0032 02 465 9162 Fax: 0032 02 468 2430
IT Power Ltd The Warren, Bramshill Road Eversley Hants RG27 OPR, United Kingdom	Tel: 0044 734 730073 Fax: 0044 734 730820
International Solar Energy Society (ISES) PO Box 124 Caulfield East Victoria 3125, Australia	Tel: 0061 3 571 7557 Fax: 0061 3 563 5173
Renewable Energy for African Development & Renewable Energy Training Institute 121 C St NW, Suite 512 Washington DC 20001 United States of America	Tel: 001 202 383 2557 Fax: 001 202 383 2555
Solar Energy Industries Association (US) 122 C St NW Washington DC 20001 United States of America	Tel: 001 202 408 0660 Fax: 001 202 408 8536
Solar Electric Light Fund (SELF) 1734 20th Street NW Washington DC 20009 United States of America	Tel: 001 202 234 7265 Fax: 001 202 328 9512

in the areas of clean coal technologies, nuclear energy, renewable energy and the promise of the ‘hydrogen economy’.²²

- *Global climate change science with a focus on climate change:* South Africa’s geographic position enables it to play a leading role in climate change science.²³
- *Human and social dynamics:* As a leading voice among developing countries, South Africa should contribute to a greater global understanding of shifting social dynamics, and the role of science in stimulating growth and development.²⁴

This 10-year innovation plan also recognises that a significant strengthening of the production of human capital and the institutional

environment for knowledge generation is necessary, in collaboration with international partners. This bold policy initiative should be encouraged by every country in Africa as we move forward to strengthen research and seek practical solutions in renewable energy technologies in Africa.

Conclusion and Recommendations

HRD in renewable energy should be viewed as an important strategy for fostering sustainable rural development and protection of the environment. Through well-designed training and education, responsible manufacturers and end-users will be able to recognise and accept the values which exist in renewable energy technologies.

There is a strong interconnection between renewable energy, science, technology and society, resulting not only from the interdisciplinary nature of renewable energy, but also from its singular and delicate contribution to all concerned.

Strategic interventions

Almost all countries which have made breakthroughs in promoting renewable energy technologies, education and training have also made them their priority for sustainability. In Cuba, for example, the government launched an energy education programme where the renewable energy curriculum was infused from elementary schools to national level and at all universities and tertiary institutions.²⁵

The development of and training in renewable energy technologies depend on political will and the existence of an efficient education system.²⁶ The adequate training of local programme leaders is essential for widespread use of renewable energy systems.

Educating the youth about renewable energy

A clear government policy on renewable energy technology should be in place, especially on energy consciousness. The entire population should be educated, but particularly the youth, about energy needs, conservation and the efficiency and advantages of renewable energy technologies in empowering communities. The energy education programme should focus on creating a new culture which values and promotes the use of

renewable energy based on principles, norms and values focused on achieving sustainable development.

To achieve this, it is of paramount importance to create a simple and easy way to communicate energy issues and solutions. The mass media, for example, could play a major role in educating the targeted audience. Targeted messages are needed to promote awareness, inform, persuade, sensitise and educate. The messages should include: economic, political, environmental, scientific and technological aspects. A behavioural change in relation to energy will be the end result and this will require the instilling of a new culture of energy consciousness in society as a whole. In order to sensitise the youth, wide-ranging activities should be developed, which could include the following:

- targeted media programmes on television and radio
- targeted news articles in relevant agricultural publications and popular magazines
- field trips into areas where renewable energy is used
- youth projects related to renewable energy technologies, and
- inclusion of renewable energy technology competitions in agricultural shows.

First priority: Training the trainers

Energy education is a continuous, dynamic and progressive process which requires actions directed to the development of a system of knowledge, procedures, skills transfer, behaviours and attitude changes in connection with the sustainable use of energy. In the long term, energy education is the key and most cost-effective method for saving energy and promoting energy use efficiency and renewable energy technologies. Therefore a national educational programme on energy should be introduced and taught at all levels throughout the country. The mass media should promote energy use and demonstrate the importance of using renewable sources of energy and applying energy efficiency measures.

The first priority will therefore be to educate the trainers and educators themselves, including agricultural extension officers. The majority of teaching staff and extension officers are likely to require theoretical and practical training relevant to renewable energy. In addition to factual information, most trainers are likely to benefit from training in the use of participatory methods for the dissemination of these energy technologies. In primary schools, training might be achieved through

broad-based project approaches to renewable energy, including interviews with members of the community.²⁷ In colleges and universities this training would help to develop research and development agenda, with students being able to relate to on-farm problems through discussions with farmers and other end-users. These participatory methods would also benefit extension programmes, helping them to evolve from using the traditional 'top-down' training to 'learning from farmers' and participatory problem-solving with members of rural communities.

Renewable energy education

- *Primary education:* The value and use of renewable energy technologies should be implicit within any primary school topic dealing with agriculture and rural life. Ideally, since almost all the school subjects address energy issues, whether it is in an explicit way, as in the case of Physics, or implicit, as in Geography or Social Studies, energy issues can be taught at all levels.²⁸ For example, in a Geography class students can list the different renewable energy sources and map their application in the various maps and future uses. In a Physics class students can study the impact of using electricity generation on the environment. And in Social Studies students can investigate and report on how newspapers and magazines provide articles and news on using renewable energy sources.
- *Secondary education:* At secondary level, learners begin to study Physics, Biology and Chemistry. At this level, learners start to understand the working principle behind a number of renewable technologies such as biogas plants, PV cells and hydropower stations. The syllabus can be redesigned to include a topic related to renewable energy sources and the sustainability of the environment within a chapter on energy.
- *Tertiary education:* At colleges and universities renewable energy should be included within agricultural curricula. Such institutions should also undertake detailed studies of various technologies available and farmers' situations and needs in relevant fields (socio-economic, engineering and animal health). In this way training and research could overlap constructively.
- *Mass education (communication and public awareness):* The mass media can play an important role in educating the general public about renewable energy. Special weekly or daily television

and radio programmes can be prepared that address energy issues, focusing on renewable energy sources. Articles on renewable energy, efficiency and use should appear regularly in all national newspapers.

In most African countries, farmers and potential users of renewable energy technologies are able to receive radio and television broadcasts and in some countries they have access to cellphones and the internet or telecentres. These can be very useful media outlets to create awareness of, educate about and promote renewable energy.

It is also useful when television frequently presents reports on renewable energy use during prime-time viewing, with greater emphasis on hydroelectric, biogas and solar thermal and PV facilities. This will enhance awareness and create a platform for informing the population and for creating a sustainable energy culture.

Renewable energy training

- *In-service training:* Many training staff and extension officers require theoretical and practical training relevant to renewable energy issues in Africa. They also need training in the use of participatory methods to help them disseminate the technologies effectively and learn from farmers.
- *Training methodologies:* Emphasis should be placed on community-based participatory approaches. Trainees should as far as possible be exposed to a wide range of situations in which renewable energy technologies are used.
- *Renewable energy demonstration/resource centres:* A series of renewable energy demonstration centres should be established in African countries. These should be closely associated with existing agricultural educational institutions. They should also be closely associated with local farmers.

Reports have stated that the future of humankind requires an energy revolution based on sustainability, HRD and the use of renewable energy at various levels.^{29,30} Africa, as part of the necessary global energy revolution, has begun its own path towards a new energy paradigm using concepts such as distributed generation, efficiency, energy-awareness campaigns and the use of PV systems in various countries. However, while there is an increased level of exposure of energy issues in the mass

media, what is being done in the field of energy education, including the training of human capital, is still insufficient to ensure that energy use and sustainability are at a more acceptable level. It is therefore necessary to implement various initiatives aimed at promoting an energy culture at various levels.

More sustainable development can only be guaranteed with an energy supply that protects the climate and the environment. 'Only if the world takes the sun's path, will there be a sustainable future for humankind. We don't inherit land from our parents but rather we borrow it from our children and grandchildren'.³¹

Recommendations

The following short-, medium- and long-term strategies are recommended for rectifying the current shortage of proper education, training and extension in renewable energy:

In the short term, the emphasis should be on awareness programmes and this, along with renewable energy, should be part of the revised curricula of primary and secondary schools and tertiary institutions. In addition, a programme for training trainers should be instituted as well as an international information exchange, through networking and preparing educational materials, including books and videos.

In the medium term, a series of renewable energy training centres should be established in various countries. These should be closely associated with existing agricultural educational institutions. They should also be closely associated with local farmers. These could be centres of knowledge with expertise in renewable energy research and resource materials. They would focus on both training and research and could also operate mobile training units that could serve farmers and other educational institutions in the field.

In the longer term, participatory research and extension programmes should be undertaken to further improve renewable energy technology and to identify further training and research needs.

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5 Investment requirements for Africa to lead in renewable energy production and distribution

Salma Hussein, Walid El-Khattam and Mohamed Abdel-Rahman

Introduction

Africa possesses significant renewable energy potential. The challenge is how to provide financing frameworks that enable exploitation of these resources in an economical, social and sustainable manner. Renewable technologies have high upfront costs compared to conventional energy technologies. Consequently, renewable energy is generally unattractive to investors. The problem is even more pronounced in Africa, where access to affordable finance is already difficult. Creative financing approaches for renewable energy development in Africa have become critical to the development of a new energy future for Africa.¹

The finance sector approaches investments in renewable energy in the same manner as for any other investments. Renewable energy investments, however, have certain peculiar characteristics that require an additional level of understanding: namely, the influence of policy and regulation on the viability of an investment, including the legal basis and durability of any subsidies, grants, tradable certificates or tax credits. These factors predominate in basic financial analyses.

From a positive perspective, conventional analysis shows the costs of production of renewable energy systems to have decreased significantly. However, the costs still remain high compared to fossil fuels. This chapter describes the requirements for the investment in electricity in general with an emphasis on renewable energy resources.²

Electricity Industry Structure

The electricity industry comprises three subsectors: i) generation, ii) transmission and iii) distribution. Since electrical energy cannot be stored, electricity has to be produced and consumed at the same time. A control centre is responsible for keeping this balance between generation and consumption. Transmission and distribution are natural monopolies. They both constitute bottleneck facilities. Furthermore, they are the stumbling blocks which, if removed, would allow competition and private-sector participation in the generation activity.³

Generation

Electricity generation activity depends primarily on the availability of primary energy resources, whether fossil or renewable resources. The following is a brief summary of the African potential for electricity generation from its various sources:⁴

Hydropower generation

Large hydro: Africa has massive hydropower capacity, of which less than 7 per cent has been harnessed. Plans are underway to exploit some of this potential. A major potential power project in Africa is the extension of the Inga River hydroelectric scheme in the DRC, which could generate 50 000 MW of power.

In overall terms, most countries in East and Southern Africa rely heavily on hydroelectric power. South Africa, Mauritius and Zimbabwe are exceptions, with the bulk – 83 per cent – of their electricity being generated from thermal sources (mainly coal). Dams were traditionally built for irrigation reasons. Electricity has been a by-product. In that sense, hydropower has always been perceived as cheap, clean energy. In recent interactions, a return of 11 to 13 cents per \$/kWh was proposed; this highlights the inability of African economies to support those projects, especially under conventional financial instruments. However, natural resource-backed transactions have proved effective. Moreover, the environmental impact of dams on the downstream and human settlements must be carefully studied and considered.⁵

Small hydro: Small hydropower is often categorised as mini- or micro-hydro, and refers to the harnessing of power from water on a small

scale (a capacity of less than 10 MW). Small hydro has the advantage of multiple uses: energy generation, irrigation and water supply.⁶ In addition, small hydropower is a very reliable technology that has a solid track record.

Much of the unexploited potential for small hydro lies in remote areas of Africa. East and Southern Africa are endowed with a large number of permanent streams, rivers and tributaries that provide excellent hydro-power development potential. However, small hydro use in the region is still largely underdeveloped.⁷

Thermal power generation

Thermal power generation depends on the availability of fuel, whether oil, gas or coal. Environmental considerations have favoured gas over oil and coal. The cost is entirely dependent on the price of fuel, which may amount to 40 to 50 per cent of the cost of the produced electricity.

Nuclear power generation

Nuclear power generation provides cheap electricity. However, the present technology favours larger units (800 to 1 000 MW units). Those sizes are not adequate for the African grids. However, pebble-bed technology, if it manages to overcome its technical problems, is envisaged as producing economic units of 150 to 200 MW.

Wind power generation

The intermittency of wind and the technical properties of the generators used make wind power generation an unsuitable option for strong grids. Among renewable energy resources wind is the most promising technology thus far. Much of Africa straddles the tropical equatorial zones of the globe and only the southern and northern regions overlap with the wind regime of the temperate westerlies. Therefore, low wind speeds prevail in many SSA countries, particularly in landlocked nations.

In SSA, South Africa is the country with the highest wind potential. For example, wind speeds of 7,2 to 9,7 m/s have been recorded around Cape Point and Cape Agulhas. The North African coast is another attractive wind speed region. Large-scale wind power generation projects that exploit this abundant wind are now underway in Egypt. Other countries in the North African region experience relatively low wind speeds.

Solar power generation

Solar power generation depends either on photovoltaics (PVs) or on the thermal effects of solar radiation. Both are still more expensive than thermal power generation. However, it is expected that the technology will bring the cost down. Direct solar energy can broadly be categorised into solar PV technologies, which convert the sun's energy into electrical energy, and solar thermal technologies, which use the sun's energy directly for heating, cooking and drying.

Substantial research has been conducted over the years on exploiting the vast solar energy resource. Today, solar energy is used at various levels. On a small scale, it is used at the household level for lighting, cooking, water heaters and solar architecture houses; medium-scale appliances include water heating in hotels and irrigation. On an industrial scale, solar energy is used for pre-heating boiler water for industrial use and power generation. Desertec and Plan Solaire are two ambitious plans to harness the great solar potential of the Sahara Desert. Furthermore, the African Union (AU) has taken a decision to promote solar energy on the continent.⁸

Geothermal power generation

Depending on their geological structure, some countries – for example, Kenya and Ethiopia – are endowed with geothermal generation potential. The technology is similar to thermal electricity-generation technologies.

Geothermal energy is the natural heat from the earth's interior stored in rocks and water within the earth's crust. The main source of this energy is the constant flow of heat from the earth's interior to the surface. This heat creates the molten rock, or magma, beneath the surface crust. Volcanoes, geysers and fumaroles are the visible evidence of the great reservoir of heat, which lies within and beneath the earth's crust. The magma heats the surrounding rock structures and when underground water comes into contact with this heat, geothermal fluid is formed. This energy can be extracted by drilling wells to tap concentrations of steam at high pressures and at depths shallow enough to be economically justifiable. The steam is then led by pipes to drive electricity-generating turbines. At an international level, approximately 8 100 MW of geothermal power is generated out of a global potential of 60 000 MW.⁹

Geothermal power exploitation has a number of advantages over other energy sources. Among the benefits of geothermal power are the near-zero emissions, and the little space required for geothermal power development compared to other energy sources, such as coal-fired plants. Geothermal power plants require approximately 11 per cent of the total land used by coal-fired plants and 12 to 13 per cent of land occupied by other renewable energies.

Transmission

Once electrical energy has been generated it needs to be transmitted in bulk volumes to load centres. Therefore, a substation with step-up transformers is used to transmit the power over a long distance at elevated voltage levels. For larger amounts of energy transmitted over long distances high voltage direct current (HVDC) technology can provide a valid option. Transmission projects are characterised by their long logistics process for easements, land clearances and compensations. Numerous interconnection projects are under study or under construction throughout the continent, including ZIZABONA (linking Zimbabwe, Zambia, Botswana and Namibia) in the south, OMVG (Gambia River Basin Development Organisation) in the west, and Kenya Ethiopia in the east. Transmission and interconnectors constitute the unlocking of infrastructure that will catalyse the potential for private-sector participation.

Transmission is characterised by relatively low capital expenditure, especially in urban areas. However, the cost becomes far higher in rural areas. Rural electrification is a challenge due to its high cost and relatively low revenues in comparison to urban areas.

Cash Flow in the Electricity Industry

Though the energy flows from generation to transmission to distribution, the cash flow in the electricity industry goes in the opposite direction. Distribution companies do the collections. In turn they pay for transmission and generation. Tariff structures which ensure that cost recovery, metering, collections, technical losses and non-technical losses are attained are thorny issues that blight the continent's electricity landscape. Tariff restructuring and deregulation are the cornerstones on which to build a sound financial structure for private investors on the continent.

Types of Electricity Sector Organisation

Vertically integrated utility

In this arrangement one organisation (public or private) performs all three activities: generation, transmission and distribution. All African utilities currently fall into this category.

Wholesale electricity market

In this arrangement, horizontal unbundling between the three activities exists. Furthermore, vertical unbundling of the generation company is achieved to allow competition among generation companies. In this market, generation is usually in private hands. Real competition exists among generators and wholesale buyers. A strong regulatory framework is required to regulate the transmission company that is a market leader.

Retail electricity market

In this arrangement, all electricity consumers have the right to choose their supplier. This organisation is sophisticated and is prevalent in Europe.

Regional Integration

More than 20 of the SSA countries have a population of less than 5 million. Economies are also very small – 20 countries have a gross domestic product (GDP) of less than \$5 billion. The small scale means that governments have difficulty funding the large capital expenditures associated with infrastructure development. Therefore, they need to pool resources in order to share the costs and benefits of regional resources. This has resulted in the establishment of the African Power Pools.

The desire to pool energy resources and leverage of scale economies in power sector development led to the formation of regional power pools in Southern and West Africa during the mid-1990s, and more recently in East and Central Africa. However, trade has yet to take off. Cross-border power trade accounts for only 16 per cent of the region's power consumption. More than 90 per cent of this trade is within the Southern African Power Pool (SAPP), and much of that is between South Africa and its immediate neighbours. Without physical or regulatory

impediments, approximately 40 per cent of East and Southern Africa's power consumption would be traded across national borders.¹⁰

Nature of Electricity Investment

Owing to risk factors, investors usually prefer to invest in generation rather than transmission, since transmission projects are subject to entanglement with many stakeholders during the construction phase. Furthermore, transmission lines are subject to theft and sabotage once erected. Distribution networks are localised within a certain geographic area with relatively low-technological and low-investment equipment. Electricity network assets are state strategic assets, even if they were built and run by the private sector. Any state has the power to step in and take over the whole operation. Therefore, investors are anxious to obtain guarantees for this specific case, which ensures cost recovery with the agreed rate of return (ROR). The characteristics of electricity investment are:

- *Long-term investment:* The investment period ranges from 15 to 40 years.
- *Asset specific investment:* Once built, assets cannot be used for any purpose other than was first intended; that is, if an investor or a government applies leverage in the operation phase to change the contractual conditions, the other party does not have that much space to manoeuvre.
- *Capital-intensive:* The ratio of fixed cost to variable cost is very high, especially for hydro and wind generation; this makes this investment an extremely risky operation.

Bottlenecks

Political will for regional cooperation

Regional cooperation and integration is a difficult issue. History shows that the United States had to go through a civil war to achieve regional integration; and the European Union (EU) took 50 years after two devastating wars to reach the present degree of integration. However, although the road is long and full of obstacles, mutual will and enough time will bring the vision to reality. Persistence is key to achieving regional integration.

Financial resources

Infrastructure investment is capital-intensive. Governments have traditionally financed infrastructure works with public money. However, in many African countries public finances are limited. The other option is mobilising private capital for infrastructure investment. This is a difficult task – infrastructure investment is the hardest and the most risky mode of international business from a private-sector perspective.

Financial impediments include the high costs inherent in the energy sector, including project preparation, tenders and importing commodities such as crude oil and gas. Limited access to funding is also a problem. Most countries have poor or non-existent sovereign credit ratings, limiting their access to international credit markets, and domestic capital markets are narrow.¹¹ Potentially valuable financial instruments such as project bonds are generally not available. Financial risks comprise insufficient cost recovery, elastic demand, non-payment of services, or inability to pay for services and foreign exchange risk. Some initiatives to overcome these difficulties entail investing in cost-reducing technology, using syndicated loans, expanding pension funds and project bonds, increasing partial risk guarantees, using indexing for foreign currency risk, and investing in prepaid meters.¹²

Internal market regulations

A level playing field is a necessity for bringing private capital to participate in infrastructure activities. The establishment of strong market regulations for infrastructure is thus key to mobilising investors to participate in the infrastructural activities.¹³

Regulatory impediments involve the lack of independent or impartial regulators in some countries; the lack of competition or open access to transmission and distribution networks; one-off power purchase agreements (PPA) rather than standard PPAs; weak procurement laws; inefficient or non-transparent tendering processes that result in cancelled, postponed or disputed tenders; poor contract laws; and tariffs that are set by the government with no provision for inflation or changes in cost. The regulatory risks are breach of contract, the impartiality of regulators, and the inability to raise tariffs to cover costs.¹⁴ Some initiatives include setting multi-year tariffs with automatic adjustment clauses; unbundling utilities into different components to open up competition; setting renegotiation clauses in original

contracts; and outlining performance targets for public authorities and private concessionaires.

Capacity building

The lack of human capacity to be able to bridge the gap and see eye to eye with potential investors is a fundamental problem that faces infrastructure development in Africa.

Capacity impediments include the lack of skills among public officials to manage PPAs; most local judicial systems not having the capacity to handle complex contracts or disputes; and regional and sub-national regulatory frameworks not being harmonised, which poses problems for projects that cross borders. Capacity risks consist of bureaucratic procedures that effectively halt or delay a project, changes in administrations and consequently different rules for investors, uneven policies in different countries, and nationalisation or expropriation. Some initiatives involve streamlining public agencies to minimise bureaucracy, hiring and developing individuals who have experience in PPAs, and strengthening regional PPA capacity and cooperation.¹⁵

Prerequisites for Resource Mobilisation to the African Continent's Energy Sector

Continent energy sector

- *Government support:* Talks with lenders revealed that the first criterion for considering resource mobilisation for an energy project is government support, especially if the project is the first of its kind. The support takes many forms, including sovereign guarantees against off-taker default and changes in law.
- *Strong regulatory framework:* A strong regulatory framework to ensure a level playing field for the energy project is mandatory to ensure that there is no foul play.
- *Creditworthiness of the off-taker:* A creditworthy off-taker with good governance and books in shape is a prerequisite to ensuring non-default on the payment of bills.
- *Process transparency:* The tendering, selection, and contract award process must be transparent and in compliance with international guidelines to avoid any future problems with governments.

African priorities

Previous and present studies – the Short Term Action Plan and the African Action Plan – have identified energy poverty in Africa as a major hindrance towards development and achieving the millennium development goals (MDGs). Wood is the primary source of energy for approximately 70 per cent of the population of SSA. This places immense pressure on the present forest regimes and leads to a multitude of problems, including health problems.

The development of hydropower projects remains a priority, together with the integration of transmission grids and gas pipelines to facilitate cross-border trade.

Finally, the harmonisation of petroleum regulations on the continent must be achieved.

Steps to Establish an Investment-Conducive Environment for Large Projects

Internal market regulations guidelines

Africa needs to establish guidelines, similar to current worldwide best practice, for the regulation of internal energy markets on the continent. The African Union (AU) member states should accept those guidelines. This requires an extensive harmonisation effort by the African Union Commission (AUC).

Cost of service guidelines

Cost recovery and tariff setting are the cornerstones of an appealing electricity sector. There must be a continental consensus on the rules for estimating the cost of service delivery. This requires an effort to build those guidelines based upon the present practices in the various countries of the continent.

Utilities' financial planning guidelines

Establishing the creditworthiness of the utilities on the continent is crucial to private-sector intervention. Our experience shows that investors eventually eye the creditworthiness of the off-taker together with its accounting practices as a prerequisite for engaging in further business

ventures. Consequently, a strong need exists to bring international practices to the African utilities to assist in promoting their profile.

Cross-border energy trade guidelines

Energy cross-border trade is a difficult issue to tackle. However, established guidelines for cross-border trade should increase competitiveness of the electricity industry within the continent thus increasing its appeal to private investors.

Transmission and distribution utilities benchmarking programme

Electricity transmission and distribution are natural monopolies. They require the establishment of a performance measurement mechanism to guarantee a minimum service level for the customer. Indeed, incentive regulation requires the establishment of such a mechanism in place to allow the gains of improved performance to pass through to the customer.

Regulatory agencies capacity building

A capacity-building programme for the African regulators in collaboration with their counterparts within other geographical regions should bring great benefit for the African regulators. A 'regulators' exchange programme' will help the African regulators to be fully aware of the best practice in energy regulation in Europe. It will enable the African stakeholders to understand more sophisticated energy market forms prevailing in Europe that enable regional energy trade.

Renewable energy integration into the development process

The African continent has a multitude of renewable resources, including solar, geothermal and wind potential, and lush forests. However, some of those resources are not exploited because they cannot compete with forms of fossil energy. Biomass is exploited, but in a non-sustainable manner, which is destroying forests in Africa. The challenge is how to devise a policy on renewables to realise this potential, while achieving the development goals in a sustainable manner. The incentives packages in many developed countries need to be tailored to fit a developing country environment. Feed-in tariffs and competitive bids, unless linked to other local

economic activities, may represent a drain on the domestic economy. The challenge, therefore, is to devise a policy that will maximise the benefit to the domestic economy of the renewable energy industry.¹⁶

Small and Medium Enterprises in Energy

One big advantage of a renewable project is the modularity of the project itself. This is a business opportunity for the continent's small investors. A set of legislative tools within a policy framework is needed to tap into the small and medium enterprises' (SMEs) potential to engage in the energy business in Africa. The prices offered by the renewables of Africa compete with all other types of generation, including hydro. The question is how to introduce this business in a manner that will eventually result in a spiral positive feedback loop that will lead to the economic growth of the business.¹⁷

Environmental aspects of small and medium enterprises' electricity business

The environmental aspects of the increase of activity in the electricity market by SMEs are not to be overlooked – especially, if there is a mechanism to add commercial value to those benefits. However, the focus should still always be the economic viability of the activity. Nevertheless, renewables are a valid economic option in Africa, in comparison with the status quo and present price levels within the continent.

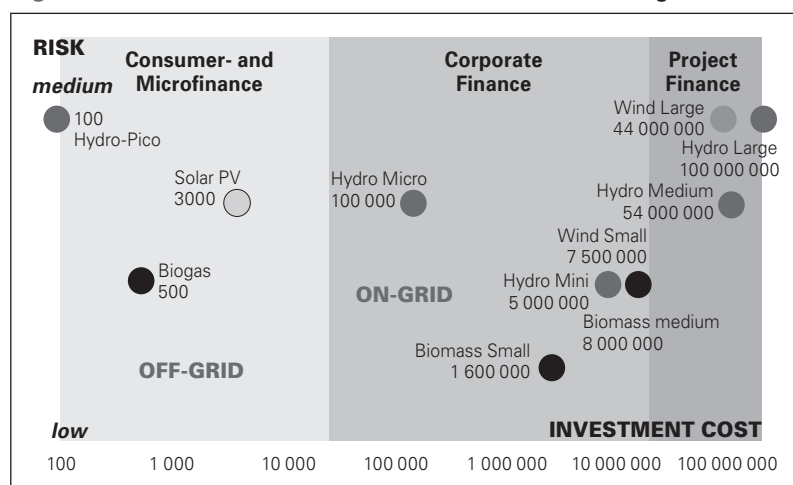
Financing Approaches in Use

The risk of different renewable energy varies widely. This gives a wide range of risk/cost combinations, as shown in Figure 5.1, which shows investment cost and risk for different types of renewable energy.

The finance can take the form of assets, venture capital, private equity, loans and grants, or multiple combinations of these. Figure 5.2 illustrates the different types of finance, the type of risk taken and an idea of the level of return, or margin, expected.¹⁹

Equity funds through private-sector renewable energy schemes for Africa

Financing in Africa tends to be a combination of private and public financing, with the latter being dominant. Most of the private investment

Figure 5.1 Investment versus risk for renewable technologies¹⁸**Figure 5.2 Types of finance and risk**

Venture Capital	Private Equity	Infrastructure Funds	Pension Funds	Bank Mezzanine Debt	Bank Senior Debt
Start ups, new technology prototypes	pre IPO companies, demonstrator technology	Proven technology, Private companies	Proven technology	Demonstrator/ Proven technology, New Companies	Proven technology, established companies
>50% IRR	35% IRR	15% IRR	15% IRR	LIBOR + 700bps	LIBOR + 300bps

****This diagram is reflective of current market conditions and is valid as at June 2009**

in Africa has focused on North and South Africa. The public–private financing models used in Africa do not necessarily guarantee timely investments. The procedures associated with these financing models are bureaucratic, complicated and lengthy. The commitment from the investors is not consistent and is largely influenced by global dynamics and perceptions beyond Africa’s control.

Recently the World Bank group has increased its commitments in new renewable energy and large hydropower facilities (more than 10 MW) in developing countries, with commitments during 2007 being \$421 billion and \$751 billion, respectively. Approximately \$735 million was committed in SSA, for 12 renewable energy and energy-efficient projects.

Carbon financing for renewable energy

At the global level various carbon-financing mechanisms are emerging. These include the Kyoto Protocol and non-Kyoto Protocol mechanisms. The Clean Development Mechanism (CDM) is one of the Kyoto Protocol financing mechanisms which can be used to finance renewable energy. However, the mechanism is in doubt since the Kyoto Protocol ends in December 2011. Furthermore, the present mechanism, with its overheads in consulting and audits, favours large projects which are not that common in Africa.²⁰

It is against that backdrop that the African Carbon Asset Development Facility (ACAD) was established. ACAD, a partnership between the UN Environmental Programme Finance Initiative (UNEP FI), the German government and Standard Bank, has announced the launch of seven green financing initiatives.²¹ The announcement follows a second round of successful fundraising at the African Bankers' Carbon Finance and Investment Forum, which took place in Johannesburg on 4 and 5 November 2010 and was organised by ACAD, with sponsorship from the German environment ministry, the European Commission and the World Bank. ACAD and UNEP both hoped to show Africa's banking sector the benefits to be drawn from investing in green development projects, and to educate bankers on the practicalities of carbon finance. The forum also highlighted the role that public-private partnerships could play in creating a skilled workforce able to tap into the potential of Africa's green economy.

Carbon trade can be an opportunity for the African renewable industry to turn unviable projects around.²²

Egypt: A Case Study of Renewable Energy Projects Development in Africa

This section discusses Egypt's present policies to encourage financing of renewable energy projects. In 1986 the government established the New and Renewable Energy Authority (NREA), which is mandated to promote renewables development in Egypt. NREA works alongside the Egyptian electricity regulator, which ensures lawful competition in the market.

Egypt is a rich country with renewable sources which can be used for power generation on a commercial scale. These sources include wind, solar and biomass resources.^{23,24} Atlases that have been developed for wind and solar energies show that two-thirds of the country area has a solar energy intensity of more than 6,4 kWh/m² day (an annual global solar

insulation of 2 300 kWh/m² year); and that in some areas, especially on the Red Sea coast, the wind speed approaches 10 m/s or even higher.

In February 2008 the Supreme Council of Energy (SCE) set a target of 20 per cent of the electrical energy mix to come from renewable sources including hydro by the year 2020. The current hydro installed capacity represents 10 per cent, but it will fall to less than 6 per cent by 2020, which means that renewable sources other than hydro need to contribute 14 per cent by 2020.²⁵ This is equivalent to installed capacity of 7 200 MW. The renewable energy strategy is that wind will represent 12 per cent of the targeted 14 per cent of the renewable energy mix by 2020 for the following reasons:

- high potential of wind energy in different sites with high capacity factor
- twenty years of experience in wind energy, supported by a current installed capacity of 405 MW
- high potential for an increasing share of local manufacturing of wind energy equipment, which could reach 30 to 70 per cent, according to the latest report issued by the Industrial Modernisation Centre (IMC) in cooperation with Cairo University, and
- electricity generated from wind resources represents a near-reach opportunity – it has the closest price to electricity generated from oil and gas.

Incentives for the private sector:

- allocation of more than 7 600 km² of desert lands appropriate for future wind projects in the Gulf of Suez and east and west of the Nile (using the results of the Egypt Wind Atlas as a guide)
- all permits for land allocation are already obtained by NREA
- environmental impact assessments, including bird migration, for potential projects
- long-term PPA of 20 to 25 years
- all financial obligations guaranteed by the Egyptian government under the PPA
- renewable energy equipment exempt from customs duties
- selling price for energy generated from renewable energy projects in foreign currency; in addition, a local portion, covering operations and maintenance (O&M) costs, in local currency
- investors will benefit from selling certified emission reductions (CERs), resulting from the implementation of the project, and

- evaluation criteria for tenders for renewable energy projects will privilege local components.

Renewable energy implementation plan

The share in the renewable energy mix for wind power plants (14%) is equivalent to installed capacity of 7 200 MW, taking into consideration a development rate of 5,5 per cent of the total sent energy and a capacity factor of 43,5 per cent. If any advances in the development rate or the capacity factor occur, the equivalent installed capacity of the wind energy could reach 8 200 MW.²⁶

A new electricity law ‘under ratification’ has adopted three mechanisms for power generation from renewable sources. These mechanisms are:

- plants built by NREA
- plants built through competitive bidding, and
- plants built through the feed-in tariff.

In addition to the market reform which guarantees third-party access, power generation from renewable sources will enjoy priority in dispatching, whenever they are available.

The New and Renewable Energy Authority’s share in the plan

The capacity of projects in the pipeline up until 2014 is 900 MW. By 2014 NREA will be producing 1 270 MW. Current installed capacity is 400 MW. NREA plans to add a further 200 MW every year from 2015 to 2020 to reach 2 200 MW. Added capacity after 2014 will be developed either through the current business model, which relies on soft financing, or through partnerships with other governmental entities.

Competitive bids

According to this approach, the grid will issue tenders to supply power from renewable energy resources. The private sector will supply 2 500 MW through long-term PPAs with the grid. The 2 500 MW will be issued in blocks of 250 MW each. The programme will include five bids, each of which will consist of more than one block, except for the first one. This will be restricted to one block to attract highly qualified international developers with strong financial status and high capacity for technology transfer.

In order to promote local manufacturing, the bid evaluation process will be based on a points system which will offer advantages for proposals that have a higher share of locally manufactured components.

The following criteria will apply in assessing the bids:

- control the increase in renewable energy capacities with reference to the capacity of the transmission system and capacity of the market to absorb
- increase local manufacturing
- increase private investment
- achieve the lowest possible prices, and
- provide the investors with guarantees through long-term PPAs.

The bidding process consists of two phases:

Phase 1: Pre-qualifications based on experience and financial status (one-year period). Qualifications include:

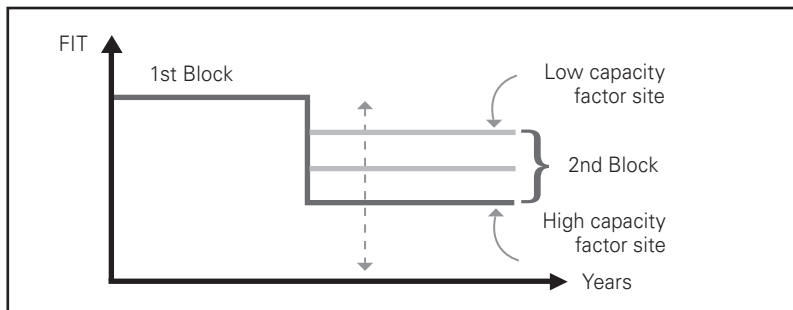
- wind measurements
- bird migrations and environmental impact assessments (EIA), and
- soil testing.

Phase 2: Shortlisted bidders submit proposals to construct and operate the wind plant.

Feed-in tariff

The goal is to reach 2 500 MW through medium and small developers. The tariff will be set for 15 years, taking into consideration the wind

Figure 5.3 Feed-in tariff design



speed and capacity (see Figure 5.3). The feed-in tariff will work hand in hand with the competitive bids mechanism, but in order to prevent overlap between the two mechanisms, competitive bids will be for large-size installations (250 MW+ wind farms), while the feed-in tariff will be restricted to small capacity installations (less than 50 MW), since international experience has shown that a feed-in tariff is more attractive to smaller investors, such as farmers, cooperatives and other private investors.²⁷

Wind power plants using a feed-in tariff

Feed-in tariffs are a vehicle to promote small and medium energy producers. The developers are categorised in terms of land ownership:

- *Wind power plants on investor-owned land:* in this case the investor is responsible for all the required studies and measurements.
- *Wind power plants on state-owned lands:* In this case wind power plants can be built in compounds so that the transmission company is able to deal with them as one power plant.

NREA will be responsible for providing the state-owned lands in areas with specified capacity, and also for all the site studies and measurements.²⁸ It is further responsible for determining the minimum technological requirements for each wind unit.

Conclusion

Promoting energy in general and energy infrastructure specifically is a challenge. This is due to the nature of this type of investment, which is asset-specific, long term and capital-intensive. Attracting investment in electricity has a number of prerequisites, including: i) the establishment of a sound regulatory framework; ii) the demolition of tariff distortions; and iii) the determination of the creditworthiness of the respective sectors. Renewables as modular generation units of relatively small size are an attractive option to engage SMEs in this business. This brings a whole set of benefits to the environment and society. Two policy instruments are used to encourage investment in renewables, namely, competitive bids and feed-in tariffs. Egypt is presented as an example of an African country that is trying to bridge its energy deficit through the introduction of renewable energies.

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6

Africa's technology options for renewable energy production and distribution

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Introduction

Energy is a key driver of economic and social development. Modern energy sources light homes, schools, hospitals, businesses and streets. They also help to irrigate crops, preserve and cook food, power industries and commerce and they further enable us to communicate and generally reduce the burden of everyday life. As energy consumption rises with increases in population and improved living standards, the challenges of access to energy, particularly to those in the developing world, become increasingly significant.

Energy sufficiency and security is key to development and prosperity as it provides essential inputs for socio-economic development at regional, national and sub-national levels.¹ Although the MDGs do not explicitly mention the provision of energy as one of their objectives, it is an unavoidable and undeniable reality that access to modern energy services such as renewable energy technologies is a strong stimulus to social and economic development. Energy provides mobility, heat and light and fuels the machinery that drives the global economy.²

The development of the renewable energy sector is fundamental to a sustainable energy future. Renewable energy sources have considerable potential to increase their contribution to meeting mainstream energy needs. While this is the case, there is a problem of integrating them into the supply system. This is due to the fact that much attention has been

focused on energy generation with little or no mention of the distribution/supply system. Today's growing emphasis on renewable energies has prompted much discussion about how these alternative fuel and electricity sources can be transported from remote wind or solar farms to the population centres that need the energy.³

The use of renewable energy technologies such as biogas can serve as a means of overcoming energy poverty, which poses a constant barrier to social and economic development in Africa. Domestic biogas has a direct relationship with three of the eight MDGs. These are MDG 1 (target 1), which seeks to achieve full productive employment and decent work for all, including women and young children; MDG 3 (target 4), which strives to eliminate gender disparities at all levels by 2015; and MDG 7 (target 9), which seeks to integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources.

The inability of many African countries to provide good, adequate energy services has been a major constraint on the achievement of the MDGs and their development. Renewable energy technologies can play a vital role in this regard. Renewable energy technologies in general offer developing countries some prospect of becoming self-sufficient with regard to energy supplies at national and local levels, with potential economic, ecological, social and security benefits.⁴

A variety of renewable energy technologies are currently available. These provide attractive, environmentally sound technological options to Africa. Renewable energy technologies could offset a significant proportion of foreign exchange that is used for importing oil. In addition, renewable energy sources are modular and well suited for meeting decentralised rural energy demands. The modular nature of most renewable energy technologies and the low investment levels required for some of them mean they are suitable for capital-constrained African countries. Most renewable energy technologies use locally available resources and expertise. This means that they provide employment opportunities for the local population.

Some of the renewable energy resources such as solar and wind cannot be controlled to provide directly continuous base-load power, or peak-load power when needed, due to the intermittent nature of their availability. Renewable energy can be generated centrally and distributed for use near its point of production. Providing energy at (or near) the point of use reduces the infrastructure required for energy distribution and energy delivery losses, and increases energy efficiency.

Emerging trends have shown that the growing need to use the available abundant renewable energy resources requires effective planning and the assessment of available infrastructure in order to select the best possible options for African states. The success of renewable energy technologies in Africa has been limited by a combination of factors, which include: poor institutional framework and infrastructure; inadequate renewable energy technology planning policies; a lack of coordination and linkage in the renewable energy technology programme; pricing distortions which have placed renewable energy at a disadvantage; high initial capital costs; weak dissemination strategies; a lack of skilled manpower; poor baseline information; and weak maintenance, service and infrastructure. All of these combined suggest a need for Africa to pursue energy security and supply options that will not thwart but will rather promote social, economic and industrial growth.

This chapter presents a critical appraisal of Africa's modern energy technologies for renewable energy. It highlights issues of scale and location-specific attributes. A critical review of different renewable energies is presented, the state of renewable energy technologies in Africa is discussed and country-specific examples and classifications are listed.

Africa's Renewable Energy Potential

Renewable energy sources available in Africa are hydropower, modern biomass, geothermal, wind and solar energy. The total hydropower potential for Africa is equivalent to the total electricity consumed in France, Germany, the United Kingdom and Italy.

The Inga River in the DRC holds great potential for hydropower generation in Africa, with an estimated capacity of 40 000 MW. In fact, the DRC alone accounts for more than 50 per cent of Africa's hydropower potential; other countries with significant hydropower potential include Angola, Cameroon, Egypt, Ethiopia, Gabon, Madagascar, Mozambique, Niger and Zambia. Despite low usage, large-scale hydropower so far provides more than 50 per cent of the total power supply of 23 countries in Africa.

Abundant biomass is available for the provision of process heat, gasification, heat cogeneration, and liquid fuels, biogas and solid-fuel production. Several agro-based industries on the continent, such as wood-based industries, palm oil producers, rice mills, sugar, and paper and pulp manufacturers use their waste to produce both process heat and power, which in most cases is used locally. Cogeneration from agricultural waste

holds great potential for Africa. For example, cogeneration contributes as much as 40 per cent of the total electricity generated in Mauritius. With increased efficiency of use and better technologies, most of such facilities can produce significant power to be used for local demand or to sell to the national grid. At present, several African countries produce sugar and have the potential to generate power for their own needs.

Geothermal energy is an untapped renewable energy source that is present in abundance in many parts of Africa. Geothermal sources have the potential to generate up to 14 000 MW. However, only a few countries, such as Kenya, have used it commercially. As at mid-2011, Kenya has installed up to 127 MW, amounting to approximately 17 per cent of the national power supply, followed by Ethiopia with a 7 MW installation. Plans to use geothermal energy in Uganda, Tanzania and Eritrea are at different stages.

Solar energy projects are limited in Africa because of cost constraints. Detailed feasibility studies have established that Africa has great potential for concentrated solar thermal power generation from desert areas such as the Sahara and Namib, with competitive power production costs about 4–6 c/kWh. So far, only South Africa operates a solar thermal power system plant, generating 0,5 MW. Egypt plans to install solar thermal plants of 30 MW by 2010 and 300 MW by 2020. Several countries in North Africa are planning to develop solar thermal plants of varying capacities, buoyed by interest from European countries. What is obvious in Africa is that the current energy policies and systems have failed to provide the platform needed to migrate to renewable energy.

State of Renewable Energy Technologies in Africa

Generally, Africa's energy sector is best understood in the context of three distinct regions: North Africa, which is heavily dependent on oil and gas; Southern Africa, which depends on coal, and the rest of SSA, which relies largely on biomass.⁵ Apart from these distinct regions, there are numerous renewable energy sources in Africa. These include the geothermal energy in the Rift Valley escarpment, hydropower in Central Africa and the solar potential of the Sahel countries. At present, only a small proportion of this potential renewable energy is exploited. For instance, of the 54 countries in Africa, 21 can economically exploit hydropower. However, only 7 per cent of the potential hydropower is exploited, particularly in Egypt, Zambia, Mozambique, Ghana and

Nigeria.⁶ On the other hand, geothermal potential is approximately 6,5 GW, but only 202 MW is currently exploited in Kenya. Finally, solar irradiation in Africa ranges between 5 and 7 kWh/m² per day and yet only 1,3 per cent of the world photovoltaic (PV) capacity is produced.⁷

Details of the state of renewable energy technologies and the potential in each of the different regions in Africa are given below.

North Africa

There are disparities in the energy resources in North Africa. Tunisia, Algeria and Egypt entirely rely on natural gas, whereas Libya depends on oil and Morocco on coal. The proportion of energy resources used for electricity generation (shown in Table 6.1) reflects the differences in resource endowments in the North African region. Libya and Algeria are net exporters of oil and gas and Egypt is a net exporter of gas only. On the other hand, Tunisia and Morocco are net energy importers. Tunisia has long been a net exporter and only became a net importer of primary energy from 2001.

The pressure exerted by economic growth, increasing population and desalination needs have increased the demand for electricity in the North African region.⁹ The underlying challenges for Tunisia and Morocco are how to achieve energy security and a stabilised supply in order to reduce dependence on imported energy. On the other hand, Algeria, Libya and Egypt are keenly looking at ways in which they can maximise energy exports and how they can continue being exporters of energy despite the increasing local demand.¹⁰ Thus, an energy policy aimed at meeting future North African energy demands is urgently required.

Table 6.1 Proportion of electricity generation from different technologies in North Africa⁸ (2006 data)

Source	Algeria	Egypt	Libya	Morocco	Tunisia
Coal	0,0	0,0	0,0	58,1	0,0
Hydro	0,6	11,2	0,0	6,9	0,7
Gas	97,2	72,1	40,9	12,8	84,9
Nuclear	0,0	0,0	0,0	0,0	0,0
Oil	2,2	16,1	59,1	21,4	14,2

Abundant opportunities for renewable energy exist in North Africa.¹¹ Thus, exploiting renewable energy has been chosen as one of the policy options for meeting the energy demand in the region.¹² A number of plans and initiatives have been outlined for exploiting renewable energy.¹³ For instance, the government of Tunisia outlined plans for solar power development in order to diversify their energy sources. Forty projects have been planned for the period 2010 to 2016, of which 29 are privately financed.¹⁴ The government of Morocco is undertaking a \$9 billion solar power project to produce 2 000 MW of electricity by 2020. Algeria, in turn, has set a national goal to provide 10 per cent of energy demand from renewable energy by 2025 from concentrated solar power (CSP).

Southern Africa

The southern African region is also relatively rich in conventional and renewable energy resources. These include coal, crude oil and hydropower resources. Significant oil reserves are found only in Angola. Coal reserves, on the other hand, are found in South Africa, Botswana, Swaziland, Mozambique and Zimbabwe. South Africa alone, however, accounts for 90 per cent of the total coal reserves in Africa. The hydropower potential is substantial in Zambia, Mozambique and Angola. Biomass in the form of wood-fuel, charcoal and crop residue is considerable in all the countries in Southern Africa and is used mainly in the household subsector.

Table 6.2 Potential annual production of renewable energy in southern Africa relative to current annual domestic energy consumption¹⁵

Country	Relative potential
Angola	27,9
Botswana	22,4
Lesotho	1,4
Malawi	6,4
Mozambique	23,4
Namibia	100,5
South Africa	1,3
Swaziland	1,6
Zambia	25,2
Zimbabwe	8,0

The potential for technologically feasible renewable energy in the southern African region is shown in Table 6.2.

As seen in Table 6.2, all the countries in the southern Africa region have considerable potential for renewable energy relative to their current consumption. Namibia has the highest annual potential from solar and wind and this is about 100 times more than the annual energy consumption. Even South Africa, a highly energy-intensive country, has a potential which is 1,3 times greater than its annual consumption.

East and Central Africa

The East and Central African region has a high potential for geothermal energy because of the geological formations of the Great Rift Valley escarpment. The estimated potential for geothermal energy capacity in the region is more than 15 000 MW. Kenya is the only country that is currently exploiting geothermal power and there is great interest in such investment on the part of countries such as Burundi, the Comoros, Djibouti, the DRC, Rwanda, Ethiopia, Kenya, Tanzania, Uganda, Zambia and Eritrea.¹⁶ The potential annual production of renewable energy in

Table 6.3 Potential annual production of renewable energy in East and Central Africa relative to current annual domestic energy consumption¹⁷

Country	Relative potential
CAR	90,9
Chad	77,3
Burkina Faso	15,9
Guinea-Bissau	14,2
Tanzania	14,1
Kenya	6,5
Uganda	3,1
Congo Republic	43,6
Sudan	27,6
DRC	24,7
Eritrea	9,5
Ethiopia	8,5
Burundi	2,2
Rwanda	0,7

these regions is shown in Table 6.3. The Central African Republic (CAR) has the highest renewable energy potential relative to its current consumption, particularly in solar and hydro energy.

West Africa

The energy situation of countries in the region is distinguished by two features: (a) biomass dominates the energy balance (ligneous fuels account for between 52% and 90% of consumption of final energy), and (b) there is a low consumption of modern energy due to the low electrification rate (between 5% and 45%).¹⁸

The countries in the region have large renewable energy resources and, for this reason, they can plan a significant role for clean energy. This is clearly indicated in Table 6.4, which shows the solar radiation, wind speed and hydropower potential of selected West African countries.

The potential of renewable energy in West African countries relative to the current annual consumption is presented in Table 6.5. As in the case of East and Central Africa, West Africa has a good relative potential for developing renewable energy.

Requirements for Successful Take-off of Renewable Energy Technologies in Africa

For a successful take-off, Africa should develop regional, sub-regional and national strategies to acquire renewable energy technologies. This can be

Table 6.4 Solar, wind and hydropower potential in selected West African countries¹⁹

Country	Solar (kWh/m ² /d)	Wind (m/s)	Hydroelectricity (MW)
Benin	unavailable	unavailable	238
Burkina Faso	5,5	2–4	200
Côte d’Ivoire	4–5	unavailable	1 650
Guinea-Bissau	unavailable	unavailable	unavailable
Mali	6,0	unavailable	1 050
Niger	6,0	2,5–5	273
Senegal	5,4	2,5–5	1 000
Togo	4,5	2–3	224

Table 6.5 Potential annual production of renewable energy in West Africa relative to current annual domestic energy consumption²⁰

Country	Relative potential
Mali	58,4
Niger	50,4
Gabon	20,3
Cameroon	12,7
Senegal	12,5
Benin	12,5
Sierra Leone	10,1
Côte d'Ivoire	9,6
Guinea	9,0
Togo	8,9
Ghana	5,7
Gambia	2,7
Equatorial Guinea	0,9
Comoros	0,2

achieved through expanding their R&D capacity, skills of technology adaptation and development, and manufacturing capacity. Technologies are successfully transferred mostly to countries that not only have developed their domestic capacities to operate the transferred technologies, but also have the capacity to modify, adapt and improve the technology through domestic innovation, that is, the desire to master the technology.

Past technology relationships in Africa have mainly been one-way relationships through licensing or commercialisation of the public sector's R&D. African countries should now enter into two-way relationships with technology suppliers using different instruments, including co-production, standardisation of components across models, modularisation and exploring new forms of sub-contracting.

Improving domestic capacity to adapt, modify and innovate technology requires national systems of innovation to be developed, but on a sub-regional basis because of their financial and human resource

demand. Policies will be required to foster technology transfer and also assist with building capacity. These will include policies that promote and strengthen the domestic knowledge base, stimulate learning and innovation, and create the support structures to sustain these processes.

Another set of policies will be those that create facilities for starting up SMEs, as these will prove useful for sub-contracting. Specific skills are required for operating, modifying, producing and innovating renewable energy and energy-efficiency technologies. Although most African countries do have operating skills and some modification skills, they will need both productive and innovative skills to match technological change. These capabilities will assist African countries to develop export-oriented skills from renewable energy technologies, such as acquiring codified knowledge, learning to meet quality standards and delivery times, and gaining the skills that will enable them to react flexibly to changes in products and processes.

Many of these skills can be acquired in a technology incubator, which is also useful for the commercialisation of technologies. Scaling up renewable energy technology markets in Africa will need to be guided by market-oriented R&D. Whereas developed countries tend to lead in cutting-edge R&D, Africa is better off focusing its R&D on issues that will have an immediate impact on its energy situation.

In addition, there is a need for coordinated R&D at local, sub-regional and regional level so as to maximise comparative advantages and increase specialisation. Regional research efforts could be strengthened by creating a regional network of R&D institutions/efforts on renewable energy similar to the global consortium that exists for agriculture.

In selecting and prioritising renewable energy technologies, Africa needs to consider technological maturity, reliability and financial feasibility. As such, Africa is, in the immediate term, better off concentrating on renewable energy technologies that are mature and will have an immediate and direct benefit on the energy situation of the continent. There is a need to address the fluctuations and intermittency of energy supply from renewable energy technologies through integrated systems, the pooling of several decentralised renewable energy systems to form energy-generating clusters, and better integration into national grid systems using multiple connections so that the grid is always supplied with minimum power in case of failure by one system. Equally important is the need to use modern technologies to address the intermittency of power generation from renewable energy technologies.

Conversion Technologies for Renewable Energy Resources Available in Africa

A key factor in Africa's effort to migrate from the predominant use of fossil energy to renewable energies is the cost of harnessing energy from its vast renewable energy resources compared to the cost of energy derived from fossil resources. Conversion technologies for renewable energy resources are a major determinant of this cost. These technologies will play a major role in determining the continent's envisaged energy migration. Thus far, the cost of harnessing energy from many renewable energy resources exceeds that of fossil fuels on the market due, in part, to the expenses associated with renewable energy conversion technologies. Renewable energy resources in Africa can meet the continent's energy demand, but for this to happen, the right energy conversion technologies have to be matched with the right resources, and cost efficiency relative to fossil energy prices has to be achieved. The performance and costs of conversion technologies largely determine the competitiveness of renewable energies.²¹ As such, renewable energy conversion technologies have to be part of the overall energy strategy of Africa in its quest to achieve its development goals. A useful advantage of renewable energy technologies is that many of them are suitable for rural areas and therefore can play an important role in poverty-alleviation efforts in many African countries.

Against this background, this section reviews conversion technologies for renewable energy resources that are being applied on the continent. Key renewable energy conversion technologies relevant to the continent are discussed according to each renewable energy resource. An overview of how each technology works is provided. Specific technology attributes, including feasible operation scale and location prerequisites, are considered. The focus is on conversion technologies pertaining to biomass, hydro, solar and wind energies, which are deemed to be the most relevant renewable energy resources for the continent in the immediate future. Technologies pertaining to marine and geothermal power are recognised; however, these are not discussed, as they enjoy, as yet, only limited use. The section also highlights the conversion technologies that provide high potential for the continent to harness energy for each renewable energy resource. It proposes that progress in the identified conversion technologies be systematically monitored with a view to introducing them to the continent at an appropriate time.

Biomass conversion technologies

One renewable energy resource that has been harnessed by Africa and still holds big potential for it is bioenergy or biomass. Biomass is widely used to generate electricity, heat homes, fuel vehicles, and even to provide process heat for industrial facilities. Biomass energy, which is derived from a wide range of natural organic fuels such as wood, charcoal, agricultural residues and animal waste, is often used in its traditional and unprocessed form in most African countries. The chemical composition of these materials, though, is important in the development of technologies to derive energy from biomass.

Broadly, there are two technologies for generating energy (heat, electricity and fuels) from biomass – thermochemical conversion and biochemical conversion technologies. The thermochemical technologies, broadly, involve the heating of biomass at different temperatures and with different air content to change its content to generate energy. The most common thermochemical conversion processes are pyrolysis and gasification.²² These technologies are explained briefly below.

Pyrolysis

This is one of the oldest technologies for deriving power from biomass. It can be traced back to ancient Egyptian times, when the process was used to produce tar waterproofing for their boats.²³ Pyrolysis involves the burning of biomass with limited air (oxygen) to yield charcoal and volatile matter that can be used to provide energy. The pyrolysis process can be conventional, fast or flash. Under conventional pyrolysis, biomass is slowly heated to yield charcoal content and gaseous energy products. In fast pyrolysis, biomass is heated rapidly at high temperatures in the absence of air, especially oxygen, which results in the production of higher quantities of liquid and gaseous products than charcoal. Flash pyrolysis is still in its development phase. It involves instantaneous heating of biomass to maximise the yield of gaseous energy products.

Pyrolysis conversion technology has been improving worldwide. Pyrolysis can now produce energy fuels with high fuel-to-feed ratios, making it the most efficient process of biomass conversion. It has the potential to compete with and eventually replace non-renewable fossil fuels.²⁴ By and large, though, the commercial production of liquid fuels from biomass using pyrolysis technology is still less competitive than conventional fossil fuels, but the efficiency of the

technology has been improving fast in recent years, raising the expectation that the technology may become market competitive in the foreseeable future.^{25,26}

Gasification

Gasification is another old, but much improved, technology that is used to extract energy from biomass. It is a thermochemical conversion technology that converts carbonaceous biomass into combustible gas called 'producer gas' and small quantities of tar and ash. It is carried out at very high temperatures to maximise gas production.²⁷ The producer gas from the process can be used to provide industrial power, generate heat and as fuel in vehicles. During the Second World War, almost a million gasifiers were used to run cars, trucks and buses.²⁸ The momentum for the use of gas fuels from biomass was not sustained as the cost of fossil energy decreased. Recent concern over the use of non-renewable fossil energy has, however, brought new interest in gasification. But the main purpose of biomass gasification remains the production of low or medium heating-value gas which can be used to generate heat and electricity by direct firing in engines, turbines and boilers.²⁹

Gasification can also produce other fuels such as methanol and hydrogen. Hydrogen is expected to take a prominent role as vehicle fuel in the future. However, hydrogen fuel entails high handling costs that make its use uncompetitive in the foreseeable future. Of notable importance with regard to gasification is the Fischer-Tropsch Synthesis (FTS) technology that produces biofuels and green diesel from biomass. Sasol in South Africa is applying and undertaking further research into FTS as a method of producing liquid fuels from biomass efficiently.³⁰

There are many types of gasifier that differ in terms of their hydrodynamics; however, the two main examples are fixed-bed gasifiers and fluidised-bed gasifiers. Fixed-bed gasifiers have reactor vessels in which biomass material is packed or moves as a plug, with gases following in between the particles.³¹ It is still the most suitable method of biomass gasification. Fluidised-bed gasifiers are a more recent development that takes advantage of the excellent mixing characteristics and high reaction rates of gas–solid contact.³²

Biochemical conversion technologies, on the other hand, fall into three categories: (a) digestion, (b) fermentation, and (c) extraction. In digestion, biomass is decomposed through bacterial action in the absence of oxygen in order to produce biogas (methane) and carbon dioxide. The decomposition takes place in a digester that may vary in

size, depending on the scale of the operation. Fermentation involves producing ethanol from biomass materials rich in sugars, starch or cellulose. Sugar cane is one of the major materials used in the fermentation process, although feed stock of wheat, sugar beet and wood is also usable.³³ The fermentation process typically involves mixing water and the sugar-rich biomass with yeast in a storage facility. Yeast oxidises the sugar and converts it into methanol. Via a distillation process, ethanol is finally extracted from the methanol. Extraction involves crushing seeds with a high oil content such as soya beans, groundnuts and sunflower seeds in order to extract the oil, which is converted into biodiesel by esterification.

A key prerequisite for the application of biomass conversion technology is the existence of bio-feedstock. Specific to the biochemical technologies, this can be viable at very small household levels as long as the household can generate or source the feedstock. The initial investment is not substantial and the technology employed is not sophisticated, and therefore the operation does not require specialised skills. Hence, the technologies can be applicable in the upper southern African countries and all countries across Africa's equatorial belt. It should be noted that biochemical conversion technologies are often water-intensive. As such, apart from reliable supply of biomass feedstock, access to water is critical for biochemical technologies. As for thermochemical conversion technologies, these are fairly sophisticated, have relatively high start-up costs and require specialised skills for implementation. Owing to the relatively high start-up costs, they may not be feasible on a very small scale.

Biomass conversion technology in Africa

Despite the existence of new technologies that increase the efficiency of energy extraction from biomass and the energy products that can be obtained from biomass globally, rural Africa generally continues to use the outdated technology of biochemical conversion that concentrates on the extraction of biogas and biofuels from animal manure and plant feedstock, respectively.^{34,35} Efforts to acquire technology to increase the energy harvest from biomass have tended to focus on animal manure; this approach limits the scope of technologies that the continent has sought to acquire and master.

Along the continent's equatorial belt, charcoal burning – a crude form of pyrolysis – is a major activity in rural areas. Charcoal is the main source of energy for cooking in the Great Lakes Region countries such as Uganda,

Kenya and the DRC. Under the practice, biomass feedstock, especially wet wood, is piled up and covered with soil. The pile of wood is burnt using a slow-burning fire at its base. After two days of the slow-burning process, charcoal is harvested and sold commercially. Since the charcoal-producing process is done in an *ad hoc* way and in a non-controlled environment, all other resultant gas energy is lost. In fact, the charcoal burners in many African countries are unaware there is another energy form that they produce but lose. A negative side effect of charcoal burning has been rapid deforestation, to the extent that it is questionable whether this form of biomass energy harnessing is indeed a renewable energy source.

There have, however, been efforts to improve biomass energy harnessing and use on the continent, in particular to increase the number of derivable fuels. The continent produces three biofuels: (a) bioethanol, made from starch-rich crops such as cassava and maize; (b) biodiesel, made from oil rich seeds including soya and jatropha; and (c) biogas produced from the biological breakdown of organic matter (animal or human wastes and other biomass).³⁶ Several African countries – including, but not limited to, Botswana, Burkina Faso, Burundi, Côte d'Ivoire, Ethiopia, Ghana, Guinea, Lesotho, Namibia, Nigeria, Rwanda, South Africa, Uganda and Zimbabwe – have installed biogas digesters.^{37,38} In producing liquid fuel from biomass, South Africa is the only country on the continent that has made progress with pyrolysis and gasification technology. Sasol, a South African company, is at the forefront of research into the production of liquid fuel from biomass.

Overall, the continent is still stuck with conventional pyrolysis and simple biochemical conversion technology to harness energy from biomass. The first step for the continent to improve its energy harnessing from biomass would be to improve current processes to achieve efficiency levels that have been reached globally using conventional pyrolysis. The next stage would be for the continent to acquire and master the application of fast pyrolysis technology. Commercial viability of this technology has been achieved in some sectors thus far. Since this technology requires low investment costs and can achieve high energy efficiencies with small-scale operations, it is potentially suitable to meet some of Africa's energy needs.^{39,40}

Hydro-energy conversion technologies

The building of dams across flowing waters, creating a reservoir and subsequently releasing the water in a controlled form to maximise the

kinetic energy of the flow has been the main hydro-energy conversion technology applied in Africa. This kinetic energy is then used to turn turbines that feed into a generator, then a converter or inverter, and finally to a transformer that converts the energy into electricity. This electricity is then connected to a grid and distributed. The electricity generated is proportional to the product of pressure head and volume flow rate. It also depends on the mechanical power produced at the turbine shaft, the hydraulic efficiency of the turbine, the density of water, the acceleration due to gravity, the volume flow rate passing through the turbine and the effective pressure head of water across the turbine.⁴¹ All major hydropower stations on the continent – the Aswan Hydro Power Station (HPS) in Egypt (3 500 MW), the Akasombo HPS in Ghana (1 020 MW), the Cahora Bassa HPS in Mozambique (2 075 MW) and the Kariba HPS in Zambia/Zimbabwe (1 320 MW) use this type of conversion technology. Innovation in the conventional hydropower conversion technologies has focused on the design of turbines and efficiency improvement in this form of energy transmission and conversion.

An alternative technology to hydropower generation, spearheaded by South Africa on the continent, is the pumped water storage (PWS) approach in which two reservoirs – upper and lower – are used. Water from a natural source is stored in both reservoirs. To generate power water is allowed to flow from the upper reservoir to the lower reservoir via two reversible pump/turbines. During off-peak periods, the water collected in the lower reservoir is pumped back to the upper reservoir using power generated from the down-flow of the water. The PWS technology converts excess hydropower into kinetic energy during off-peak energy demand periods, and then reconverts the kinetic energy into hydropower during the peak demand periods. The Electricity Supply Commission (Eskom) in South Africa has two PWS schemes – the Palmiet Pumped Storage Scheme in the Western Cape and the Drakensberg Pumped Storage Scheme in KwaZulu-Natal. The Pumped Storage Scheme, sometimes referred to as 'Pumped Hydro Energy Storage' (PHES), offers a greater range of operational flexibility in lieu of intermittent rain patterns and subsequent water flows.⁴² Apart from the case of South Africa, PHES technology is not yet in commercial use on the continent, however: as the effects of change in climate on African rivers increase and water levels of lakes continue to recede, the introduction of PHES technology to new hydropower stations is almost inevitable.

In terms of location attributes, hydro-energy projects require a reliable natural water source. Hence they can be a feasible alternative energy

source only for those countries with permanent rivers. In Africa these include southern African countries that share the Orange River, East African countries that share the Nile River, the Congo Basin countries that share the Congo River, among others, and West African countries that have a number of rivers, including the Niger River. In the dry countries of the continent, such as Namibia in the southern African region and most of the countries that share the Sahara Desert in North Africa, hydro-energy generation is largely not feasible. Hydro-energy conversion technology is also most feasible in large-scale operations. This is due in part to the initial high costs of starting up hydropower projects. This explains why hydropower stations on the continent are mainly situated on major rivers in Africa. Technology for micro-hydropower stations is available. It consists of a scheme that diverts water from a river using a dam or weir. The water is transported to the forebay using a canal or pipeline. From the forebay the water is taken to the turbine by the penstock. The turbines drive a generator either directly or by means of a mechanical transmission.⁴³ Although the micro-hydropower conversion technologies are mature, overall the undertaking of micro-hydropower generating projects is not yet competitive compared to power generation from fossil fuel. It is expected, however, that as the technology improves, micro-hydro energy production in Africa will become economically viable and competitive. Therefore it is critical that stakeholders on the continent keep abreast of new developments in micro-hydropower conversion technologies.

An emerging technology in hydro-energy harnessing is the River Current Energy Conversion Systems (RCECS). RCECS are electromechanical energy converters that convert the kinetic energy of river water into other usable forms of energy.⁴⁴ They use an ultra-low-head turbine that will operate on the equivalent of less than 0,2 m of head.⁴⁵ In the use of RCECS an inclined horizontal-axis turbine is inserted into a flowing river, with a transmission mechanism that powers a generator through to a power converter. Their setup costs are projected to be minimal compared to the conventional construction of river dams to create reservoirs. Given that major rivers on the continent already have hydropower stations but hydropower availability on the continent still remains low, the introduction of RCECS downstream has the potential to augment further the hydropower generated in Africa's rivers. Thus far, the use of RCECS technologies has been tested on the White Nile River in Sudan,⁴⁶ and in the DRC, with satisfactory efficiency results.⁴⁷ RCECSs can possibly be built, operated and maintained using local resources and skills,

and with proper low-tech design and financing, such turbines could be appropriate technologies for developing countries.⁴⁸

Solar energy conversion technologies

Application of solar energy conversion technologies in Africa for heating and/or electricity, particularly at household level, is prevalent across the continent. The technology used can broadly be divided into two categories: solar electric (or PV) systems and solar thermal systems. The former technologies generate electricity from solar power for use in a wide range of devices, including water pumping, and the latter technologies are used mainly for tapping heat from solar energy. PV systems are made up of solar cells connected in series and made out of purified silicon. PVs use a chemical–electrical interaction between light radiation and a semi-conductor to obtain direct current (DC) electricity. The energy produced is dependent on the intensity of the sunlight, hence their output varies with the sun's intensity. A typical solar module comprises 36 cells connected in series to produce an operating voltage of 12 V.⁴⁹ Conversion technology improvement for solar energy has focused on improving the efficiency of the solar cells.

Solar thermal systems comprise solar thermal plants, solar water heaters, solar drying, solar cookers, solar distillers and solar coolers. Solar thermal plants use a complex concentration of solar collectors to produce a high enough temperature to produce steam to drive electricity-generating turbines. The concentration systems fall into the category of point-focus concentrators such as central receiver systems and parabolic dishes, or line-focus concentrators such as parabolic-trough collectors.⁵⁰ This technology is still under development and has not yet been applied on a commercial scale in Africa. Solar water heating involves having a solar heat collector and a water storage facility. A transmission means is created to transfer heated water to a water storage facility, while allowing cold water to flow to the solar heat collector.

Solar drying is the simplest and the most widely used solar process on the continent, particularly to dry agricultural produce. This process involves exposing the produce to solar heat in order to dry it. As yet, no significant progress has been made using this technology. The solar cookers are either ovens or stoves that make use of solar energy. Although mature technologies in developed countries exist, solar distillation and solar cooling technologies are not widely spread on the continent.⁵¹

Solar technologies in Africa

PVs have been installed in most rural areas in service stations across the continent to provide lighting and cooling for dispensaries and schools. Solar thermal technology, on the other hand, has taken the form of improved stoves and water heaters. In East Africa, the solar energy sector is the most developed due, in part, to international support programmes in the region that sponsored and encouraged people to use PV at household level.⁵² Solar PV home systems have been successfully adopted. Solar water heating had been successful in the North African region and South Africa, though, on average there are more failures than successes on the continent as regards use of the PVs and solar thermal technologies.^{53,54}

Algeria has the highest solar energy potential on the continent. It has a combined wind and PV installation of 2,353 MW in 906 villages. However, the level of technology being used is still rudimentary.⁵⁵ In 2006 solar PV installations in Nigeria produced in excess of 350 kWp.⁵⁶ In South Africa, Eskom is promoting the increased installation of solar water heaters as a way of reducing overall energy demand.

Essentially, solar conversion technologies need high levels of sun radiation. Sites to tap solar energy should be free of obstructions. A major disadvantage with solar power is that it requires good storage facilities since the energy is not available all the time. PV systems have to include a battery bank for energy storage and a charge controller that regulates the power flow into and out of the battery bank. Moreover, since most commercial PVs are made of silicon, which is an expensive material, the cost of PVs has tended to be unaffordable to an average household in rural Africa.

With the exception of a few countries along the equator with year-long high rainfall – such as Gabon and Equatorial Guinea – the whole of Africa has adequate solar radiation to sustain a solar energy harvest throughout the year. A notable advantage of solar energy that has contributed to wider use and application of the related conversion technologies is that the technology is fairly mature on the continent and the running costs, after installation, are not significant.

Wind energy technologies

The process of harvesting energy from wind includes the conversion of the force of wind – kinetic energy – acting on rotor blades into rotational

energy, and finally into torque or mechanical energy. Rotational energy is used either to generate electricity or to power machines or equipment such as mills or water pumps.⁵⁷ The intermittent energy of wind energy, however, necessitates a means of storing energy during off-peak times to be used in peak periods. Intermittent wind energy also means that for its practical use, the energy has to be supplemented by other energy sources such as hydropower to accommodate periods of low-feed kinetic energy. The need to supplement wind energy with yet another energy source in order to make it reliable is a major disadvantage in making wind an appropriate power source for energy-starved areas in Africa because it requires a dual investment.

Wind energy conversion technologies have focused on maximising energy transformation and transmission from kinetic, rotational through to electricity, on the one hand, but, on the other, increasing efficiency in storing the generated energy.

Although wind conversion technology is relatively easy to master with low maintenance costs, wind plants require high initial investment, which means that, for such projects to be economically viable, there should be a significant demand for energy to be produced. Without a significant market to support a wind energy-producing plant, the project is not likely to break even in the estimated 15-year project life. By implication, small projects for harvesting wind energy are less likely to be economically and financially viable. Moreover, the wind energy conversion projects are location-specific. There should be enough wind to keep the rotors rotating. In the context of Africa, wind energy conversion projects are feasible only in areas of high power demand with strong winds. This double requirement means wind energy would be useful in much of the continent, but it is not feasible in the foreseeable future with existing technology. Wind turbines can generate from 50 kW to 5 MW, but, as indicated above, the generation of low-energy output is not economically and financially viable.

Wind conversion technologies in Africa

Although Africa has some of the highest wind velocities in the world and enjoys a maximum exposure to sunlight, most African countries have been slow to exploit sources of alternative power. South Africa, Morocco, Egypt, Kenya, Tanzania and Ethiopia are the main actors in wind-energy harvesting on the African continent. Egypt and Morocco are countries with the largest installed capacity. Africa's

cumulative installed wind energy capacity was 1 014 MW in 2009 – a mere 0,63 per cent of the world total.⁵⁸

In the southern African region, a wind farm at Klipheuwel on the West Coast near Cape Town in South Africa generates 3,2 MW using the Vesta and Jeumont turbine technologies. Vesta technologies incorporate conventional induction generators with gearboxes, whereas Jeumont technologies use a permanent magnet synchronous generator without a gearbox. For full operation, the turbines require wind speeds of between 47 and 57 km/h, although they can start generating at between 11 and 15 km/h.⁵⁹ The wind speed requirement highlights the importance of site selection for locating wind turbines. On the coast north of Cape Town, Darling Wind Power, an independent producer, generates about 5,2 MW of power, using geared wind turbines with induction generator technologies. In Port Elizabeth, South Africa has begun installing 25 turbine farms each of which will have a 1,8 MW capacity and be able to produce energy to power approximately 1 700 households. The first turbine was commissioned in November 2010. The project is being implemented by a Belgium-based renewable energy company, Electrawinds. The technology used in the project is the Vestas Converter Unity System (VCUS). The wind turbine is a Vestas V90 with a 95 m tower and a 90 m rotor. It is designed to maximise energy capture for medium wind regimes (IEC IIA) and to further improve upon the V80's reputation as a reliable performer. Features of the Vestas include a primary bed-frame structure made from casting to optimise load transfer to the tower and increase overall frame stiffness. The new turbine also has an improved main-bearing housing design for increased structural stiffness, standard Low Voltage Ride Thru (LVRT) capability to provide continuous operation through grid faults, and complete variable speed capability with VCUS technology.

The turbine systems used in harnessing wind energy can either be fixed or variable speed. For the fixed-speed turbine system the induction generator is directly connected to the electrical grid. The rotor speed of a fixed-speed wind turbine is determined by the gearbox ratio and the generator pole-pair number. In the variable-speed turbine system, the stator is directly connected to the grid, while the rotor winding is connected via slip rings to a converter.⁶⁰

Mozambique has started a wind-energy generation pilot project generating about 10 MW and using geared turbine technologies, but it is premature to make a qualified statement on economic feasibility of the project. There are also small wind-energy generating projects in Zimbabwe and Malawi using the same technologies.

In East Africa, Tanzania has installed wind turbines expected to generate at least 100 MW of power at full capacity in Singida. In Kenya, about 365 giant wind turbines are to be installed in the desert around Lake Turkana in the north of the country to create the largest wind farm in Africa. The turbines to be installed will use Vestas V52 technology, as in the case of South Africa. The technology incorporates computer systems that optimise the use and efficiency of the turbines. Turbines are equipped with sensors to determine undesired vibrations and allow the computer controlling system to take preventive measures. These sensors also make it possible to control the rotors individually, adjusting the angle of each blade independently during every rotation, which improves the efficiency.⁶¹

In North Africa, on the coast of the Red Sea in the vicinity of Hurghada, Egypt has installed wind turbines that produce 310 MW in the Zafarana area. Specifics of the technologies used in the wind harvesting in Egypt are unavailable. It is known, however, that a local company SWEG had plans to manufacture wind energy generation components.⁶² Both Egypt and Morocco have research centres that focus on renewable energy technologies. Egypt has the Hurghada Wind Energy Technology Centre (WETC), which specialises in wind measurements and wind-turbine performance testing. Knowledge generated by the centres is shared with industry.

Morocco has the Centre for the Development of Renewable Energy (CDER). Major wind farms in the country include the Dahr Saadane wind power plant in Melloussa (140 MW) which uses turbine technology from Gamesa, a Spanish company, and has a total of 165 wind turbines. Gamesa technology permits the production of segmented wind turbine blades and the handling of long blade spans enabling the production of more efficient and high-energy output turbines.

Even in places with fairly stable high wind flows, the challenge of converting highly variable wind energy input into a steady power outflow remains. The challenge necessitates technologies that allow the turbines to be effectively driven by varying wind speeds. Initially, technologies used electronic converters and transformers for this purpose. However, this could only be achieved at additional cost. The VCUS technology is one of the recent innovations in wind-energy harnessing. The technology uses a hydrodynamic sub-system to stabilise the speed of the output shaft driving the generator, thereby avoiding the need for a frequency converter; but it still maintains a mechanically geared system for high wind speeds. To further increase efficiency of wind-energy harvesting,

rotor performance is continuously being improved through use of larger and aerodynamically improved blades.⁶³

It is important to note, however, that the cost of harnessing wind energy on the continent is still higher than that of conventional fossil energy sources. Nonetheless, wind energy production, though at a higher unit cost, could be useful to companies and exporters to European and American markets that need environmental accreditation before they buy products or that operate in environments where a minimum consumption of green energy is required by legislation.

Industrial Ecology of Renewable Energy Technologies – A System Dynamics Approach

Industrial ecology seeks to apply the knowledge of systems in nature to the design and operation of industrial activities in order to achieve integrated and sustainable relationships between the natural world and industrial development. The most recognised application of industrial ecology is industrial parks that construct industrial zones where waste or by-products of one company can be used as resources by another business – this is termed ‘industrial symbiosis’.⁶⁴

Applying systems thinking to plan for sustainability, engineers can approach renewable energy technologies by developing scenarios for different renewable energy technologies value chains. This should involve assessing the renewable energy technology production, logistics and infrastructure, and end-use options and exploring the preferred option by identifying all issues and needs through multi-stakeholder engagement. This backcasting approach – defining a desirable future and then working backwards to identify policies and programmes that will connect the future to the present – is a key concept for a strategic sustainable development framework, by helping to define the system conditions of sustainability.⁶⁵ Decision-conferencing methods should be used to ensure that there is broad-based multi-stakeholder participation in identifying all the issues involved and identifying the criteria involved. Indicators are identified to provide a measure of the desired sustainability management objectives or criteria and the scenarios assessed to reveal the preferred option(s). Economic indicators may include costs, reliability of freighters, obstacles and cargo safety. Environmental indicators may include natural resource use, energy efficiency, air emissions, and emissions to soil and water. Social indicators may include increased access to public services such as schools

and healthcare and new business and community development opportunities.⁶⁶ In the identification and assessment of a programme or project, methods such as multi-criteria analysis can be invaluable for assisting in making preference-based decisions of alternatives that are characterised by multiple, usually conflicting, attributes. Unlike single-objective, decision-making techniques, such as benefit-cost or cost-effectiveness analysis, multi-criteria analysis approaches can take into account a wide range of differing, yet relevant criteria.⁶⁷ Even though these criteria cannot always be expressed in monetary terms, as is the case with many externalities, comparisons can still be based on relative priorities or values.

The dynamic nature of systems also needs to be considered. For example, in planning the biofuel production with logistics and infrastructure expansion in a coordinated and effective manner, a simulation model can be developed. System dynamic models can represent the internal feedback loops and time delays that affect the behaviour of the entire system.⁶⁸ This facilitates an understanding of the behaviour of the system over time and the influence of independent and dependent variables.⁶⁹ A causal loop model is initially generated to represent the relationships between inter-related factors affecting a system and to define the system boundaries. This increased understanding is greatly facilitated by workshops with transdisciplinary research teams and multi-stakeholder engagement. To generate a working system dynamics model data is required to establish the interactions between various components of the system and to define these interactions by means of differential equations and represent the results graphically.⁷⁰ The construction of these models can assist in special strategic planning and facilitates policy formulation by means of forecasting.^{71,72} The creation of a working model allows forecasting and also temporal planning, since the time delays incorporated in system dynamics models allows close integration of the material and energy flows in the entire value chain from production to consumption.⁷³ These models can also be used to reveal the responsiveness of the system to such changes in materials production to consumption, thereby providing a systems approach for greening the entire value chain.⁷⁴

Conclusion

As the world migrates to renewable energy sources, it is necessary to ensure that this new era of energy revolution supports all aspects of social and economic development. Drawing on the socio-economic impacts of

fossil-fuel-based industries, it can be said that the era of fossil-fuel-based sources of energy has had a significant impact on human development. The impacts of fossil fuels on social development are clearly magnified in chemical and energy industries that resulted from the exploitation of fossil fuels. Energy industries use energy content of naturally occurring chemicals such as liquids and gaseous hydrocarbons. Chemical industries use the material content, which constitutes the complex array of organic molecules, that have been synthesised for use as a feed, to a series of complex organic chemical products and processes. These constitute the set of complex industrial systems that emerged from fossil fuels. The combined effect of this has been the creation of various industrial processes and industries that either supply raw materials or use by-products of refined fossil fuels.

Renewable energy provides an environmentally sound technology option for Africa's sustainable development. The modular nature of most renewable energy technologies and the low investment levels makes them particularly suitable for Africa. This means that the migration from fossil fuels to renewable energy sources is an absolute necessity for Africa. In this process renewable energy conversion technologies will play a significant role, as they have a strong bearing on the final cost of renewable energy relative to fossil-derived energy. With the available conversion technologies on the continent, renewable energy harnessing still cannot compete with fossil-fuel energy. However, the technology is improving fast and it is highly likely that renewable energy competitiveness will be achieved in the medium term. Against the background of low uptake of new renewable energy technologies on the continent and the general lack of formal structures through which the continent can keep up to date with renewable energy conversion technology developments, it is recommended that structures or institutions be put in place whose mandate would be to systematically monitor identified renewable energy technologies with a view to introducing them to the continent at an appropriate time.

Renewable energy technology distribution is critical, as it affects price and availability. Renewable energy can be generated centrally and distributed for use near its point of production. Providing energy at (or near) the point of use reduces the infrastructure required for energy distribution and energy delivery losses, and increases energy efficiency. Finally, renewable energy technology production and distribution needs to take place in a framework of sustainable development that considers economic, social and ecological issues.

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Conclusion and Recommendations

It appears as if a new scramble for Africa has begun. This time it is not for its mineral resources but for its sun, wind and fertile land. Unfortunately, despite all its natural wealth, Africa still lags behind in developing and accessing clean renewable energy. The continent still relies on biomass for its energy. This source of energy, although abundant, is being exploited in an unsustainable manner.

In assessing the possibilities that exist in Africa to migrate fully to renewable energy sources, this publication began by looking at the wealth of sources of renewable energy on the continent. These resources range from the sun belt across the Sahara Desert in the north to the Kalahari Desert in the south. Excellent wind resources lie at the Gulf of Suez in north-east Africa and on the coastline of Morocco in North Africa. The Rift Valley system is a unique geothermal resource in the east; and hydropower resources are spread all over the continent, from the east to the west.

In addition, the nuclear energy sources, where the continent once had cutting-edge capabilities, need to be revived by the continent's role players. The South African nuclear programme, for instance, requires a concerted effort by and support from the continent to bring it back to life.

Investment in renewable energy infrastructure is an area in which Africa should focus its attention and resources. The scattered nature of energy infrastructure in Africa means that the continent has the potential to deploy renewable energy infrastructure without rendering

current infrastructure obsolete. International and regional financial institutions, together with local governments, can play a critical role in this. There are many bright spots on the continent where projects can be initiated to satisfy domestic energy demand.

On policy direction, there is a need for a pan-African movement to formulate an African position on renewable energy. International experience shows that there are two possible ways of presenting incentives: competitive bids and feed-in tariff systems. Formulating policies that will fit the domestic economies of all African countries is a matter that still needs to be pursued. The present form of feed-in tariffs or competitive bidding appears to drain local economies. Inviting private role players will require some effort on Africa's part, bearing in mind the need to protect domestic interests, while establishing an environment that is favourable to encouraging private investment. A useful first step would be to determine the creditworthiness of Africa's national economies.

Regional integration is a vital part of setting up large projects. This, however, will require gaining strong political backing, which is a tremendous task. Thus, the best option in the short and medium term would be to enhance the participation of SMEs in the energy business. Access to carbon credit finance will also have to be considered if African projects are to be kick-started.

Recommendations

To assist the process of transition to renewable energy sources, the creation of an environment that is conducive to investment in renewable energy is recommended. This should entail the development of:

- internal market regulation guidelines
- cost-of-service guidelines
- utilities financial planning guidelines
- cross-border energy trade guidelines
- transmission and distribution utilities' benchmarking programmes
- regulatory agencies' capacities
- the participation of SMEs in the energy sector
- Africa's nuclear capabilities, and
- hydrogen-based economies.

Energy Transition in Africa

The world's demand for energy coupled with a decreasing stock and supply of fossil fuels is propelling the transition to renewable sources of energy. This global movement presents many opportunities and challenges to Africa. If Africa can identify the opportunities and start to position itself, with its abundant sources of renewable energy, it stands a chance of being a global player in the production and supply of renewable energy.

Achieving this will, however, require a combination of effective planning and investment on infrastructure, skills and technology. In determining how this should be done, this publication has brought together some of Africa's leading experts in the field. The book sets out a foundation for Africa's role in harnessing renewable energy by highlighting an ideal mix of investment, resource use, skills development and infrastructure management which the authors believe Africa needs in order to migrate successfully to a green economy that is supported by renewable energy.

In policy terms, a pan-African approach is required to drive African policy on renewable energy that will cater for Africa's economies. This should also demonstrate a political will to carry the policy through and to establish an environment that encourages private investment as well as providing access to carbon credit finances.

In this new era of what has been termed 'the second scramble for Africa', the authors' views on Africa's potential to supply renewable energy present hope that Africa can lead in the supply of renewable energy.



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